The Milky Way, like many large galaxies, is gobbling up its smaller neighbours

Galactic cannibals

Mike Irwin, Geraint Lewis and Rodrigo Ibata

Looking up at the sky on a dark night immediately reveals two things: First, there are a lot of stars visible, and secondly, the stars are not evenly spread over the sky but are concentrated in a broad band – the Milky Way. Throughout most of human history, the Milky Way was little more than an astrological curiosity. Since the advent of the astronomical telescope, however, people realised that there are many more stars in the sky than can be perceived by the naked eye. These stars are accompanied by glowing gaseous nebulae and dark patches of dust, as well as other 'fuzzy' nebulae, some showing spiral structure. The key to resolving the 'problem of the spiral nebulae' was to determine their distance. This was finally achieved by Edwin Hubble who, in 1923, measured the distance to the great spiral nebula in Andromeda, finding it to lie far beyond the distance to any of the stars.

We now know that this nebula, the Andromeda Galaxy (M31), is the closest spiral galaxy to our own, at a distance of 'only' two million light years.

With a lot of detective work, the structure of the Milky Way Galaxy was eventually determined and was found to be very similar to that of Andromeda: most of the 100 billion or so stars are confined to a rotating relatively flat disc, possessing prominent spiral structure and containing large amounts of gas and dust; there is a small central bulge thought to harbour a black hole with a mass equivalent to a million Suns; a sprinkling of stars in a roughly spherical halo; and a satellite retinue of a few hundred globular clusters – each a concentration of a million or so stars. As the Sun is located within the disc, 30,000 light years from the centre of the Galaxy, our view of the night sky can be easily explained; the broad swathe of stars we call the Milky Way represents our view through this spiral disc.

The Local Group

We also now know that large galaxies are generally accompanied by a retinue of smaller satellite 'dwarf' galaxies containing only a few hundred million stars each, and that even these large galaxies are not simply scattered at random through the Universe, but are preferentially found in groups, or clusters. These associations contain between a few and several thousand galaxies. The Milky Way and Andromeda are just the two largest galaxies dominating a system of around 40 or so galaxies making up the Local Group of galaxies.

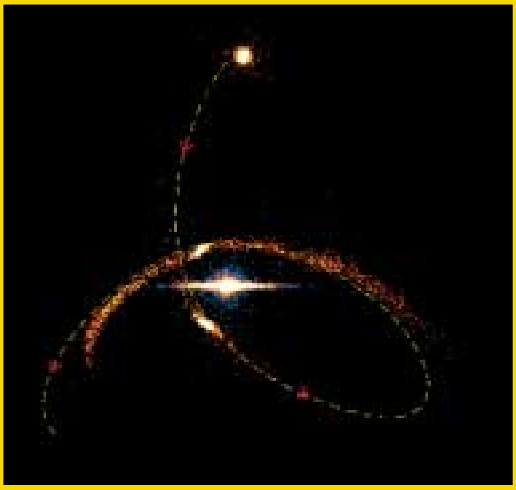
Our Local Group is believed to be representative of the Universe at large, and modern cosmological theory makes exquisite predictions how this form of ordered structure arises as a natural consequence of the Big Bang and the subsequent hierarchical gravitational interactions. One prediction of cosmology is that massive galaxies grow by rapidly accreting 'dwarf' galaxies. So, are the satellite systems we see today in the Local Group the leftovers from this process, or is it still ongoing? If the latter, what would be the signature of a partially digested satellite galaxy?

The figure on the near right summarises the fate of a dwarf galaxy that wanders too close to the strong tidal field of the Milky Way. At the top, we see the dwarf before it falls into the gravitational well of the Milky Way. The closer the dwarf gets to the centre of the Milky Way, the stronger the tidal forces become and the more the dwarf is stretched. As its orbit takes it past the galactic centre and back out to greater distances, the tidal forces are severe and stars are ripped from the dwarf in both leading and trailing debris trails which closely follow the original orbital path. As this process continues, the tidal tails grow evermore extensive, eventually encircling the host galaxy and the dwarf dissolves away into nothing but tidal debris.

Spectacular evidence that this process seemed to be occurring around the Milky Way was uncovered in the 1970s with the discovery of an enormous arc of neutral hydrogen gas 'trailing' the Magellanic Clouds, at the time thought to be the two nearest of our satellite companion galaxies. Sceptics, however, were quick to point out (correctly) that this apparent debris trail may not solely be the work of gravitational tidal fields but could be the result of some other physical process, such as 'ram-pressure stripping' (in other words, pushing the neutral gas out via its movement through the gaseous halo of our Galaxy). Despite much effort, no convincing stellar counterpart to the Magellanic Stream has been detected and the consensus now is that although tidal effects contribute to the phenomena, ram pressure effects must also play a prominent role.

M31 located at a distance of two million light years, the great nebula in Andromeda, now known to be the closest spiral galaxy to our own. If we could step outside the Milky Way and look back, this is very similar to how it would appear. The satellite galaxies NGC205 and M32 are visible respectively: above and to the right; and just below the centre

A schematic showing the fate of a dwarf galaxy that gets too close to the powerful tidal fields of a galaxy like the Milky Way



The central regions of the Milky Way showing the bulge and inner disc with its extensive dust zones. A star density map of the disrupting Sagittarius dwarf galaxy is superimposed

astronomers find signs of galactic cannibalism in action everywhere they look

And there the situation languished until the mid-1990s, with sporadic but hardly compelling claims of the detection of small possible tidal streams, alignments and so on. Meanwhile, the cosmologists were generating ever stronger arguments that growth of structure through galactic cannibalism must be occurring on all scales. Why did the Local Group appear to be so different?

First evidence of cannibalism

The situation changed dramatically early in 1994. As part of his PhD studies at the Institute of Astronomy in Cambridge, one of us, Rodrigo Ibata, was measuring the velocity of stars near the centre of the Galaxy to probe the mass distribution of the Galactic bulge. To his surprise, in addition to the predicted bulge component, a region in the constellation of Sagittarius, had an extra very large group of stars present, moving coherently and independently of the expected Galactic populations. Ibata and his colleagues speculated that this group of stars represented a satellite galaxy of the Milky Way caught in the act of tidal disruption (*Frontiers* 3, p.6). A quick bit of detective work indeed showed this to be the case. Not only were stars being accreted but also several globular clusters – another prediction of tidal capture scenarios.

The case was so compelling that six months after the initial discovery, the Sagittarius dwarf was presented at an international astronomy meeting as the smoking gun of galactic cannibalism in action. We now know that tidal debris from this system completely encircles the Milky Way, and that more than half the stars in the Milky Way halo and several globular clusters have been deposited there by it.

Ironically, several years on, astronomers now find overwhelming signs of galactic cannibalism in action just about everywhere they look. More recent evidence of large accretion events has appeared with the ability to sensitively map large regions of the sky. In January 2003, two teams of astronomers independently announced the discovery of another giant stream of stars around the Milky Way. Unlike the tidal stream of the Sagittarius dwarf, which sweeps nearly over the poles of the Milky Way, this new stream of stars lies almost in the plane of the Galaxy. At a distance of 50,000 light years from the Galactic centre, these stars lie at the very edge of the spiral disc, and ring the Galaxy like a giant doughnut. The several hundred million stars in this ring are quite old and probably represent the ghost of another dwarf galaxy that has been dissolved and is being steadily incorporated by the Milky Way.

And it's not just the Milky Way that is exhibiting clear evidence of galactic cannibalism. Our recent large scale survey of the Andromeda nebula shows that it too has been caught in the process of digesting one or more satellite galaxies.

Furthermore, as a final encore, astronomers expect that in the ultimate local melange M31 will itself collide with the Milky Way in a few billion years, rearranging the Local Group once more and replacing the two large spiral galaxies with a giant elliptical galaxy. F

__Rodrigo Ibata__ finished his PhD at the Institute in 1994 and is now a CNRS fellow at Strasbourg Observatory. __Geraint Lewis__ was also a PhD student at the Institute of Astronomy and is now a Senior Lecturer at the School of Physics, Sydney University. __Mike Irwin__ is Director of the Cambridge Astronomical Survey Unit at the Institute of Astronomy.
E-mails: *ibata@newb6.u-strasbg.fr*
gfl@physics.usyd.edu.au
mike@ast.cam.ac.uk

Web links

www.nbody.net
Images and movies of cosmological *n*-body simulations

www.cita.utoronto.ca/~dubinski
Future merger between the Milky Way and Andromeda

www.astro.wesleyan.edu/~kvj
Galactic archaeology