Dwarf Spheroidal Galaxies
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Our galaxy, the Milky Way, is surrounded by a swarm of dwarf galaxies each composed of 100 000 to billions of stars. Many of these galaxies are easy to see; for example, the Magellanic Clouds are visible to the naked eye for observers in the Southern Hemisphere. Many of the dwarfs are far more difficult to spot; some of these were discovered telescopically in the nineteenth century. One class of nearby dwarf galaxy eluded discovery for even longer. In the late 1930s, Harlow Shapley and Walter Baade reported the discovery of a new type of ‘star system’ in the constellation Sculptor (figure 1). Barely visible on their original plates, this new object was the first example of a dwarf spheroidal (dSph) galaxy ever found. It is now known to be one of nine such galaxies orbiting the Milky Way.

By convention, the nearby dSph galaxies are usually named after the constellation in which they are located (see table 1). The nine dSph galaxies closest to the Milky Way are all very likely gravitationally bound to our Galaxy. The remaining dSph galaxies listed in the table reside within the Local Group of galaxies, and all but one are satellites swarming around the nearby Andromeda galaxy. In recent years dSph galaxies have been discovered in large numbers within other nearby groups of galaxies and galaxy clusters. When these numbers of known dSph galaxies are extrapolated to the universe as a whole, it becomes apparent that dSph galaxies are by far the single most common type of galaxy by number.

If dSph galaxies are so common, how did they elude discovery for so long? Even in the darkest, most remote sites on Earth, the sky glows faintly with optical radiation. This light comes mostly from atomic and molecular emission from the upper parts of our own atmosphere, from sunlight reflected off dust scattered throughout the solar system and within our atmosphere, and from individually invisible, but very numerous faint galaxies and stars. Most galaxies have surface brightnesses comparable to that of the night sky; that is, the total light they emit over the total area of the galaxy as seen in the sky is comparable to the amount of light the sky itself emits. These high surface brightness galaxies—Spiral and Elliptical Galaxies—are the ones most commonly pictured in popular astronomy books. They represent what most people think about when they imagine a ‘typical’ galaxy. In contrast, dSph galaxies have far lower surface brightnesses, glowing faintly with a surface brightness as low as only 1% that of the night sky. These galaxies are the closest examples of true Low Surface Brightness systems.

Finding such ghostly objects would be similar to spotting a 40 W lightbulb in front of a large searchlight or discerning a 1 m rise in a 100 m tall plateau from far away. Sculptor was found in the 1930s only because it is one of the brightest nearby dSph galaxies, it is located in a particularly dark part of the sky, and many photographic plates were available by that time to confirm its discovery. Many of the most recently discovered dSph galaxies were not found by eye, but from sensitive electronic measurements of photographic images of large regions of the sky. Because they are so difficult to spot, it seems certain that many more nearby dSph galaxies remain to be discovered.

Global properties of dwarf spheroidal galaxies

As their name implies, dSph galaxies are among the smallest, least luminous galaxies known. Ursa Minor, for example, shines with a total luminosity of about 300 000 times the luminosity of the Sun. By comparison, the Magellanic Clouds—dwarf companions of our Milky Way—emit as much light as 2 billion Suns. Even some of the Milky Way’s Globular Clusters emit more light than the faintest dSph galaxies. Most dSph systems show a centrally concentrated structure with a core region of nearly constant, but extremely low, surface brightness. The outer parts of dSph galaxies slowly fade into the night sky; in many cases, no well-defined outer boundary can be measured. The central cores range from 1000–3000 light-years in diameter, while the ill-defined outer boundaries typically extend 3–10 times further out; the dimensions of the Local Group dSph galaxies (see table 1) are representative. The ultra-low core surface brightnesses...
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Table 1. Dwarf spheroidal galaxies (after Mateo).

| Galaxy | Year of discovery | RA 2000 | Declination 2000 | Parent* | Distance (million light-years) | Luminosity (million Suns) | Mass (million Suns) | Core diameter (light-years) | Outer diameter (light-years) |
|--------|------------------|---------|------------------|---------|-------------------------------|--------------------------|---------------------|--------------------------|---------------------------|
| NCG 205 | 1864             | 00 40.4 | +41 44           | And     | 2.6                          | 370                      | 740                 | 850                      | 3500                      |
| NCG 185 | 1864             | 00 39.0 | +48 20           | And     | 2.0                          | 130                      | 130                 | 500                      | 8000                      |
| NCG 147 | 1864             | 00 33.2 | +48 31           | And     | 2.3                          | 130                      | 110                 | 550                      | 10000                     |
| Sagittarius | 1994          | 18 55.1 | −30 29           | MW      | 0.08                         | 18                       | 100−1000            | 1800                     | 30000+                    |
| Fornax  | 1938             | 02 40.0 | −34 27           | MW      | 0.45                         | 16                       | 68                  | 1500                     | 7700                      |
| And II  | 1998             | 23 26.5 | +50 42           | And     | 2.5                          | 5.7                      | —                   | 520                      | —                         |
| Leo I   | 1955             | 10 08.5 | +12 19           | MW      | 0.81                         | 4.8                      | 22                  | 700                      | 2700                      |
| And I   | 1972             | 00 45.7 | +38 00           | And     | 2.6                          | 4.7                      | —                   | 1200                     | 10200                     |
| Sculptor| 1938             | 01 00.2 | −33 43           | MW      | 0.26                         | 2.2                      | 6.4                 | 360                      | 4750                      |
| And VI  | 1998             | 23 51.7 | +24 36           | And     | 2.7                          | 1.4                      | —                   | 380                      | —                         |
| And III | 1972             | 00 35.3 | +36 31           | And     | 2.5                          | 1.1                      | —                   | 390                      | 1900                      |
| And V   | 1998             | 10 10.3 | +47 38           | And     | 2.6                          | 1.0                      | —                   | 425                      | 2250                      |
| Sculptor| 1938             | 01 00.2 | −33 43           | MW      | 0.26                         | 2.2                      | 6.4                 | 360                      | 4750                      |
| Sextans | 1990             | 10 13.1 | −01 37           | MW      | 0.28                         | 0.5                      | 19                  | 1100                     | 10500                     |
| Carina  | 1977             | 06 41.6 | −50 58           | MW      | 0.33                         | 0.4                      | 13                  | 680                      | 2230                      |
| Ursa Minor | 1955           | 15 09.2 | +67 13           | MW      | 0.21                         | 0.3                      | 23                  | 650                      | 2100                      |
| Draco   | 1955             | 17 20.3 | +57 55           | MW      | 0.27                         | 0.3                      | 22                  | 590                      | 1850                      |

Notes: * Name of Galaxy about which the listed dwarf orbits. And = the Andromeda galaxy; MW = the Milky Way; none = indicates that the galaxy appears to be unbound to any identified parent galaxy.

Nearby dwarf spheroidal galaxies

Because most distant dSph galaxies appear as featureless smudges of light, we must turn to the closest dSph satellite galaxies within the Local Group to try to understand the true nature of these little, but extremely common, systems. At the time of the initial discovery of Sculptor by Shapley and Baade, it was clear that dSph galaxies were composed of stars similar to those found in globular clusters. Moreover, dSph galaxies and globular clusters were the only sorts of objects known to inhabit the outermost regions of the halo of our Galaxy. These features and the simple structure of both types of star systems seemed to indicate that dSph galaxies were simply puffed up versions of otherwise normal globular clusters.

This belief persisted for many years, but in time enough evidence accumulated to begin to suggest that something far more complicated was going on within dSph galaxies. The Ursa Minor galaxy, for example, appeared to be so extended that it could not possibly be gravitationally bound. The implication was that we were witnessing the disruption of this dwarf galaxy as it passes close by the Milky Way. The problem with this was that independent calculations of the tidal forces suggested that Ursa Minor was sufficiently far from the Milky Way that it should not yet be falling apart. As astronomers began to carry out detailed studies of the individual stars in the closest dSph systems, they confirmed that the stars in dSph galaxies are deficient in heavy elements compared with the Sun. Oddly, the global properties of the stars in color-magnitude diagrams of dSph galaxies did not confirm these low element abundances. This seemingly contradictory behavior is known as the second...
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Dwarf spheroidal galaxies throughout the universe

Every galactic group or cluster that has been adequately studied has revealed large numbers of dSph galaxies. Most of these galaxies appear to be quite similar to the ones found in the Local Group, but some interesting variations are also found. For example, the nearby MB1 group contains a few dSph galaxies that are considerably more extended and have even lower central surface brightnesses than the known local systems. Nearby galaxy clusters such as the Virgo, Fornax, Centaurus and Coma clusters contain hundreds to thousands of individual dSph galaxies (figure 2). Dwarfs with nuclei are particularly common in these environments, especially among the brighter galaxies. In most cases, the nuclei appear to contain stars that are distinctly different—possibly older or with different elemental abundances—from the majority of stars in the parent dSph galaxies.

Dwarf spheroidal galaxies appear to concentrate more towards the centers of galactic groups and clusters than any other type of galaxy, including spiral galaxies, large elliptical galaxies or the relatively dust-free SO disk galaxies. This is also observed in the Local Group where the vast majority of all dwarf companions nearest the Milky Way and the Andromeda Galaxy are dSph systems. Astronomers speculate that proximity of dwarfs to larger galaxies or the centers of large clusters helps remove gas from the smaller systems as a result of tidal forces or perhaps from interactions with isolated gas clouds also orbiting the larger systems. Either process can truncate star formation in the affected systems, allowing them to fade to very low surface brightnesses and ultimately resulting in the formation of dSph galaxies. Alternatively, dwarf galaxies near larger companions or near the dense centers of clusters may accelerate their star formation due

Figure 2. A close-up of a small region of the nearby Centaurus galaxy cluster. Five dSph galaxies within the cluster are denoted with arrows, and a sixth uncertain case is identified with an arrow and a question mark. The galaxies denoted with an ‘E’ are normal dwarf elliptical galaxies in the cluster and the elongated galaxy denoted ‘Sp’ is a spiral galaxy of the cluster viewed at a nearly edge-on orientation. Note how extremely diffuse and faint the dSph galaxies are relative to the other galaxies and to the brightness of the night sky itself. These features uniquely distinguish these dwarfs from normal ellipticals. Clusters such as Centaurus appear to be typical: dSph galaxies are the most common single type of galaxy known in the present-day Universe. This negative image was obtained at the Las Campanas Observatory of the Carnegie Institution of Washington and was provided courtesy of Kristin Chiboucas.
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Two observations do suggest that dSph galaxies may interact tidally with their massive parents. First, none of these galaxies are found extremely close to a large galaxy, implying that tidal forces destroy dSph systems that venture too near to their parents. In the case of the Milky Way, the limiting distance appears to be about 150,000 light-years. Second, we actually see one example of the disruption occurring today. The Sagittarius dSph is unique among all known dSph galaxies in its enormous size and low density, both indicative of tidal disruption. This case really does appear to be one of a dSph galaxy in its final death throes. Models of its interaction with the Milky Way suggest that within about one billion years, Sagittarius will have dissolved away as a distinct galaxy, its stars scattered through the halo of our Galaxy.

Beyond about 100 million light years, dSph galaxies appear too small and too faint to be identified easily. However, their presence may still be inferred indirectly. Deep counts of galaxies have revealed a population of so-called faint blue galaxies located at such great distances that we are seeing the systems as they appeared many billions of years ago. Some of these could conceivably be dSph galaxies caught during one of their many strong episodes of star formation. Such events make the galaxies brighter and much bluer and consistent with the properties of at least some of the faint blue galaxies observed. Faint irregular galaxies appear to have global properties similar to dSph galaxies, but with the addition of young stars and a significant interstellar medium. Perhaps these represent modern-day examples of galaxies that have undergone evolution from a young, blue phase and are changing into typical dSph galaxies. Because dSph galaxies are so common and because most popular models of galaxy formation in the early universe suggest that small galaxies formed first, it may even be possible that dSph galaxies represent the basic unit of galaxy formation. If so, the dSph systems we see today may represent fossils of objects similar to the very first galaxies ever formed.

Bibliography
van den Bergh S 2000 The galaxies of the Local Group (Cambridge: Cambridge University Press) (A galaxy by galaxy description of the Local Group; many historical comments included. All of the local dSph galaxies are included.)
Hodge P 2000 An Atlas of Local Group Galaxies (Dordrecht: Kluwer) (An atlas of photos of all Local Group galaxies including all the nearby dSph systems.)
Impey C and Bothun G 1997 Low surface brightness galaxies Ann. Rev. Astron. Astrophys. 35 267–307 (A technical review of low surface brightness galaxies that offers some insight into dSph in distant environments.)
Mateo M 1998 Dwarf galaxies of the Local Group Ann. Rev. Astron. Astrophys. 36 435–506 (A recent technical review of the Local Group including the dSph galaxies.)

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