The Stromlo Missing Satellites Survey

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Scientific Motivation

According to cosmological theory, density fluctuations of Cold Dark Matter (CDM) form the first structures in the Universe. The gravitational potential wells of these dark matter halos suck in primordial gas and provide the seeds for the formation of stars via energy dissipation and cooling, a billion years after the Big Bang. The observational Universe today is filled with these galaxies, the prime repositories of shining baryonic matter. For obvious reasons, most of the detected and catalogued galaxies are intrinsically the largest and the brightest, those that can be seen from the greatest distance and are most easily studied against the night sky. Ironically, a major limitation on our ability to develop a consistent model that describes how galaxies emerged out of dark matter comes from the incompleteness of our picture of the nearby universe, in particular from the lack of a detailed understanding of the phenomenon dwarf galaxies.

Dwarf galaxies are stellar systems composed almost entirely of dark matter with a minimum mass of the order of $10^6$ solar masses. Examples have been discovered orbiting the Milky Way and Andromeda galaxies. Extreme low star densities make them transparent and hard to find, but they seem to dominate by numbers any volume in space and were more numerous in the cosmological past. CDM theory tells us that the dark matter mini halos and their optical manifestations, the dwarf galaxies, are the building blocks of larger galaxies like our Milky Way. Hence, if we want to shed light on the nature of dark matter and understand the driving mechanisms of galaxy formation/evolution we have to spend a disproportionate amount of effort on finding and physically characterising the faintest, most elusive galaxies that exist in the Universe.

Cold Dark Matter Theory on Galactic Scales

A generic prediction of the standard CDM galaxy formation paradigm (e.g. Moore et al. 1999; Klypin et al. 1999; Governato et al. 2004) is that pri-
mary dark matter halos around massive galaxies contain hundreds of smaller clumps of dark matter. It is thought that the majority of these mini halos will gravitationally collect sufficient primordial hydrogen gas and turn it into stars to form a dwarf satellite galaxy than can be observed today. However, in our best-studied case, the Milky Way, the predicted number of dark matter clumps exceeds that of the observed dwarf satellites by a factor of \( \approx 20 \) (see Fig. 1). This current inconsistency between CDM cosmology and dwarf galaxy frequency is heavily debated in the literature and known as the *missing satellites* or *substructure problem* (Klypin et al. 1999; D’Onghia & Lake 2004).

Fig. 1. Distribution of the known Milky Way satellites out to the Galactic virial radius \( r_{\text{vir}} = 250 \text{kpc} \). Eleven dwarfs have been discovered in SDSS and 2MASS data in the last three years. The significance of the dwarfs being arranged in a plane (dotted line with the \( \pm 15^\circ \) edges as dashed lines) has been discussed by Kroupa et al. (2005) and Metz, Kroupa & Jerjen (2007). Half of the entire sky (south of \( \delta = 0^\circ \)) will be surveyed by the Stromlo Missing Satellites program.

More recently the focus has shifted to whether the observed 3D-distribution of Milky Way satellites could actually be drawn from a population of dark matter subhaloes. The concern was raised when Kroupa et al. (2005) and Metz, Kroupa & Jerjen (2007) reported that the Milky Way satellites are statistically arranged in a disk, apparently inconsistent with a cosmological substructure
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The Stromlo Missing Satellites Survey population at the 99.5% confidence level. Although Kang et al. (2005) argued that finding a dozen dwarf galaxies in a planar distribution is not improbable, debating this issue is futile as the incompleteness of the census of Milky Way satellites remains the ultimate uncertainty.

Because incompleteness hinders any serious testing and possible refinement of the current cosmological model, progress can only be expected if observers can provide theoreticians with the full picture, including a robust dwarf satellite number and accurate estimates of their baryonic and dark matter contents, sizes, and galactocentric distances. The starting point of such a task is a deep and systematic photometric inventory of all the stars in the halo of the Milky Way, a technical challenge that has become feasible just recently.

Previous Work

Northern Hemisphere: Willman et al. (2005) conducted a first systematic blind search for Milky Way satellites using the Sloan Digital Sky Survey (SDSS; York et al. 2000) covering 25% of the sky. Careful analyses of resolved stars in both the SDSS and the Two Micron All Sky Survey (2MASS) revealed a first new Milky Way satellite, Ursa Major (UMa). Since then, nine more satellites have been reported (Zucker et al. 2006; Berlukurov et al. 2007; Walsh, Jerjen & Willman 2007).

Southern Hemisphere: due to the lack of any digital imaging data until recently, the search for dwarf galaxies in the vicinity of the Milky Way generally had to rely on photographic plates (e.g. Côté et al. 1998; Jerjen et al. 1998, 2000; Karachentsev et al. 2004). For example, Whiting et al. (1999) detected the Cetus dwarf in the outskirts of the Local Group (at 780 kpc) that was faintly visible on UK Schmidt plates. Five years later, the great potential of finding new Milky Way satellites with modern technology was demonstrated when Martin et al. (2004) discovered the Canis Major (CMa) dwarf in 2MASS.

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The ANU 1.35m SkyMapper telescope at Siding Spring Observatory represents investment in Australian frontier technologies of A$13 million. It is among the first of a new breed of specialised telescopes which are capable of scanning the sky more quickly and sensitively than ever before using a 16k ×16k CCD mosaic camera with a 5.7 sq degree FOV (Keller et al. 2007; Tisserand et al., this volume). Over the next five years, that telescope is dedicated to carry out the multi-colour, multi-epoch Stromlo Southern Sky (S3) Survey generating 150 Terabytes of CCD data. The final product will be a catalogue with positions and photometry for ≈ 1 billion objects in six bands: SDSS $u, g, r, i,$ and $z$ plus an extra, Strömgren-like $v$ filter. The survey will
cover all 20,000 square degrees south of the equator (δ < 0°, see Fig. 1) and
has photometric limits 0.5 – 1.0 mag fainter than SDSS.

The various releases of the S3 catalogue will be systematically analysed
by the Stromlo Missing Satellites (SMS) team employing sophisticated data
mining algorithms that have been developed and extensively tested with the
publicly available Sloan DR4. Among others, we have announced the detection
of Boötes II (Walsh, Jerjen & Willman 2007; see also Walsh et al., this vol-
ume), a Milky Way satellite candidate with size-luminosity properties close to
SEGUE 1 (Belokurov et al. 2007), the second faintest of the currently known
Milky Way companions.

Studies of such satellite candidates with a typical baryonic content of a
few thousand stars or less require comprehensive imaging and spectroscopic
follow-up programs to separate the wheat from the chaff. If the SMS project
and the SDSS survey, probing 75% of the Milky Way’s entire sphere of in-
fluence, will find significant numbers of true dwarf satellites that populate
the same parameter space as model galaxies from high resolution simulations,
these experiments would corroborate the standard model of cosmology in a
remarkable way. Whatever the results, they will provide an unprecedented
set of observational constraints that will show how tightly baryons and dark
matter are bound on galactic scales and will energise the debate about new
physics.

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