Multi-coloured large area survey of the Virgo cluster
(the "Twr O Sêr" (TOS) survey)

Collaborators

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Summary

We are propossing to carry out a B band survey of the entire 100 sq deg of the Virgo cluster to unprecedently low surface brightness levels. In addition we intend to survey a strip $3^o \times 10^o$ across the centre of the cluster at U and Z so that we can distinguish between actively star forming galaxies and those dominated by an older stellar population. Our main interests lie in the determination of the Luminosity Function (LF) of one of the most galaxy rich regions of the nearby Universe and to derive the LF as a function of colour and position in the cluster down to luminosities equivalent to the local dwarf spheroidals. We wish to compare the star formation history of these galaxies with the proposed star formation history of the Universe (the Madau plot). We are also interested in the galaxy population down to very Low Surfaces Brightness (LSB) levels and a possible measurement of diffuse inter-galactic light (and associated stars). The survey may also be used to study the large scale distribution of faint galaxies behind the cluster, inter-galactic extinction from within the cluster and the identification of quasars that may act as probes of the inter-galactic medium. The survey and subsequent image identification and classification will provide a large data set for follow up observations using large telescopes. It will be of particular value for the optical identification of sources detected in the current 21cm multi-beam survey, in which the Cardiff group are playing a leading role.

Targets

100 *sq deg* region centred on the Virgo cluster $RA \approx 12^h\ 25^m\ Dec \approx 13^o$ (1950) in the B band. A $10^o \times 3^o$ strip in U and Z centred on the above position and running east west. Over the next 3 years (starting in semester 99A) we request 21 dark nights and 8 Bright/Grey nights to complete the survey.

Scientific Case

The seminal work carried out by Sandage and collaborators (Binggeli et al. 1984, 1985) on the cataloging of the galaxy population in the nearby Virgo cluster in many ways revolutionised our ideas about galaxy populations in the nearby Universe. They showed that the cluster is dominated (numerically) by LSB dwarf galaxies, that the LF of elliptical and spiral galaxies is Gaussian, while that of the dwarfs is a power law and that the dwarfs follow a morphology density relation similar to that of the brighter galaxies. The catalogue has acted as a prime object source for subsequent directed imaging, spectroscopy and 21cm observations. They were able to make substantial progress because long exposure high resolution Du Pont plates were available for the first time over the entire extent of the cluster ($\approx$ 100 *sq deg*). Even so, their survey was only complete to $B_T = 18$ ($M_B = -13.7$ for a $(m-M)_{Virgo} = 31.7$, $H_o = 50$) and to central surface brightness levels of $\mu \approx 24.0\ \mu_B$. It is now possible with the INT WFC, within a reasonable period of time, to extend these magnitude limits considerably to $B_T \approx 26$ ($M_B = -5.7$) and $\mu \approx 28.0\ \mu_B$ over an equivalent area (see fig 1). With 1 $kpc \approx 10$" (good seeing is not crucial) we will be able to resolve dSph galaxies and from our simulations (Morshidi 1997) we will be able to distinguish them from background galaxies (they will have very low surface brightness for their size). We will also image a significant area of the cluster in the ultraviolet (U) and the near infrared (Z). Our intention is to use the (U-B) and (B-Z) observations to act as a crude measure of the spectral energy distributions of the galaxies and so distinguish between actively star forming galaxies and those with quiecient older populations (Bressan et al. 1994).

In addition there has been a persistent problem (see Driver et al. 1994) with the interpretation of deep observations of the distant Universe - the faint surface brightness levels that they reach compared to local surveys (these, by necessity, have been photographic because of the large area coverage required to obtain a significant number of local galaxies). Thus we have a rather strange situation - we know more about distant galaxies at LSB levels than we do about galaxies in the local Universe (Ellis 1997). To compare like with like we need to observe a region of the sky over which we can maximise the number of local galaxies and so we can make realistic models for comparision with the distant Universe. At the present time more deep observations of random fields (they already exist in abundance) will not, we believe, lead to a better understanding of the formation and evolution of galaxies than would a detailed study of the Virgo cluster.

We (see Morshidi 1997, Morshidid et al. 1998a and b) have just completed (after three years work) a survey over some 2500 *sq deg* of sky using APM scans of UK Schmidt plates. Although the photographic data provides a limited surface brightness range ($\approx 23.0 - 24.5\ B\mu$) for the detection of new faint objects, we have nevertheless catalogued some 2400 LSB galaxies and analysed their spatial distribution and influence on the LF of galaxies. Compared to the bright galaxies the LSB galaxies are more extended spatially, but they are associated with the bright galaxies. Including these LSB galaxies the LF is relatively steep at $\alpha \approx -1.5$. Having just about completed this study we are now in a position to undertake another large observational and data analysis project.

The specific issues we intend to address are listed below.

1. The LF of galaxies down to the luminosity of local group dwarf spheroidals.
2. The LF (and luminosity density) of galaxies in U and Z - the luminosity density in young and old stars and the history of star formation in different regions of the cluster. Does it provide a consistent picture with that proposed by Madau et al. 1996?
3. The morphology of galaxies as a function of position within the cluster.
4. The morphology of galaxies at different wavelengths - Virgo U band observations correspond to B band observations of galaxies at $z \approx 0.3$ so we will have a large sample of galaxies from which we can determine the evolution of morphology over a significant look back time. Field surveys have insufficient nearby galaxies.
5. The extent and numbers of very LSB galaxies - the possible discovery of more galaxies like Malin 1 (Bothun et al. 1987).
6. The extension of normal galaxies to very LSB levels - the identification of shell galaxies and similar features.
7. The possible detection of intergalactic light and its relation to intergalactic stars (Ferguson et al.1998).
8. The identification of quasars ((U-B) excess) behind the cluster that can be used as probes of the intercluster medium and the halos of cluster galaxies.
9. The LF of globular clusters and how it differs for galaxies of different luminosities and types.
10. Systematic changes in the colour of background galaxies as a measure of intergalactic extinction (Zaritsky, 1994).
11. If intergalactic extinction is not a problem then these data can be used to study the properties and distribution of faint galaxies over unprecedented scales.
12. Finally the Cardiff HI group (Disney, Banks and Boyce) are actively involved in the Parkes and Jodrel Bank 21cm all sky multibeam survey. The optical identification of objects detected in the survey is of obvious importance. We will use the Virgo 21cm data to compare the distribution of HI with that of the galaxies, calculate HI to optical mass ratios and we will have redshifts accurate to ≈ 20 km/s for all galaxies with $M_{HI} > 10^8\ M_\odot$.

Our expectation is that there will be numerous other projects that other groups will use these data for.

Given the problems with sky brightness (at best 23 $B\mu$) and flatfielding (at very best 0.1% of sky), this may turn out to be the ultimate ground based survey of the Virgo cluster.

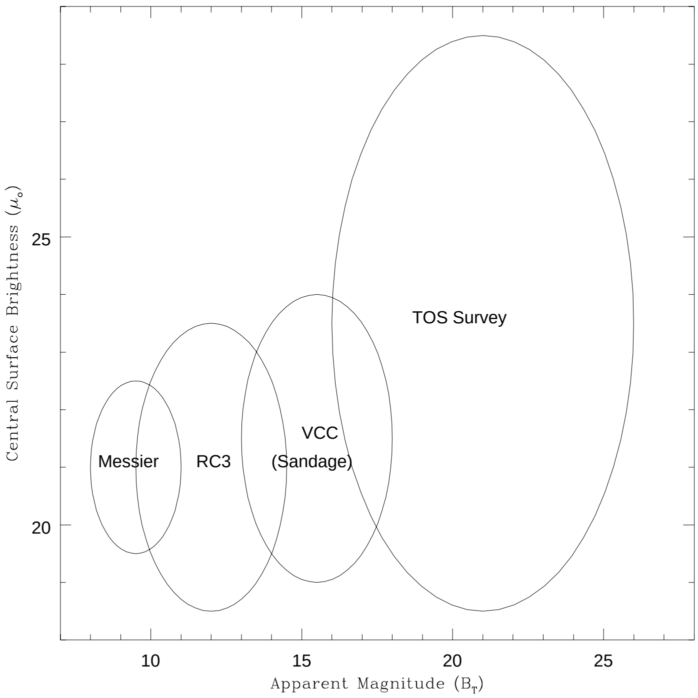

Fig. 1

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Technical description

We intend to carry out a deep survey in B over the entire 100 sq deg of the Virgo cluster and a less deep survey (given typical galaxy colours, $(U-B) \approx 0.0$, $(B-Z) \approx 2.0$) of a strip $3^o \times 10^o$ across the cluster center running west to east in U and Z. Our magnitude limit is set so that a dSph galaxy with $M_B \approx -7.0$ and $\mu_e \approx 26.0$ will be detected in all colours. To complete the U and B band survey we request 21 dark nights and for the Z band survey 8 bright/grey nights in semesters 99A, 00A and 01A. The observing times per field (each total exposure time will be split in two to remove cosmic rays) and brightness limits are summarised below

Band	Total Exp time (sec)	m_{Limit}	μ_{Limit}	Frames	Total time on source (hr)
U	1000	25.0	27.0	150	42
B	600	26.0	27.6	500	83
Z	1200	22.5	24.3	150	50

In the above calculation we assume 3 CCDs with a frame overlap of 30 arc sec giving an effective field per exposure of 0.2 *sq deg*. With overheads (readout time and calibrations, weather!) we hope to spend at least 6 hrs per night integrating on target and so we request 30 nights over the next 3 years with the first observing run in semester 99A. The Z band observations can be done in Bright/Grey time so we request 4 Bright/Grey nights in semesters 99A and 00A. The U and B band observations will require dark time and so we request 7 dark nights in each of semesters 99A, 00A and 01A.

The surface brightness limits quoted are *per sq arc sec* and can be extended considerably by smoothing and matched template detection methods (Phillipps and Davies, 1991, Davies, Disney and Phillipps 1994). We have, amongst us, considerable experience of CCD data reduction and we have already reduced WFC data from an observing run in Jan. 1998.

We will obtain standard stars throughout each night for calibration purposes and obtain a 'master' flat field from median stacking data frames which should enable us to flatfield to about 0.2% of sky.

Data analysis

R. Smith will be in charge of data analysis and if successful we would expect to allocate at least one departmental Ph.D studentship to this project. We would request two observers so that the data can be reduced in real time at the telescope. Given sufficient manpower and computing facilities we will make every effort to make the data available in a similar way to SKYVIEW. Thus anyone on the *WWW* will be able to request a deep CCD picture of a given part of Virgo. The filter set used will also enable us to make "real" colour images of the cluster in a similar way to that produced for the HDF. Thus we believe that this project will have a significant Public Understanding of Science element to it given adequate funding.

Our experience with APM data has made it clear that in many cases image parameter data (with image classification) is a much more versatile tool than the images themselves. We will run standard image detection software (SExtractor) over the data and so provide lists of objects detected for statistical studies.

Role of the individuals

Davies - project co-ordinator, LSB galaxies and intergalactic extinction.
Phillipps - the luminosity and bi-variate brightness function of galaxies.
Smith - data analysis and low level cluster light.
Banks - coordination with the all sky 21cm survey and optical follow up.
Driver - background galaxies (properties and clustering) and comparisions with the Virgo population.
Edmunds - the evolution of cluster galaxies.

* Just in case you were wondering **"Twr o Sêr"** means group of stars or constellation in Welsh.