FAINT DWARF GALAXIES IN THE NEXT GENERATION VIRGO CLUSTER SURVEY

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Abstract. The Next Generation Virgo Cluster Survey (NGVS) is a CFHT Large Program that is using the wide field of view capabilities of the MegaCam camera to map the entire Virgo Cluster from its core to virial radius. The observing strategy has been optimized to detect very low surface brightness structures in the cluster, including intracluster stellar streams and faint dwarf spheroidal galaxies. We present here the current status of this ongoing survey, with an emphasis on the detection and analysis of the very low-mass galaxies in the cluster that have been revealed by the NGVS.

1 A new generation imaging survey of the Virgo Cluster

The Virgo Cluster, the closest large concentration of galaxies in the nearby Universe, has long been one of the favorite playgrounds of astronomers. From the 32 cluster members identified by Smith [1936], to the 2096 objects in the Virgo Cluster Catalog (VCC) (Binggeli et al. [1985]), Virgo has provided large samples of galaxies of all morphological types and masses — key data to study the structure and evolution of galaxies. The VCC, despite its age — the survey is based on photographic plates obtained with the Las Campanas Dupont 2.5m telescope between 1979 and 1982 — remains the reference catalog for any study of the Virgo Cluster. More recently, the Sloan Digital Sky Survey (SDSS) has at last allowed Virgo to enter the digital age and colorized the cluster, bringing multi-wavelength shallow CCD images in 5 optical bands. Deeper surveys exist for some specific areas of Virgo: two E-W and N-S strips were mapped with the 2.5m Isaac Newton

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Telescope at a depth allowing the detection of galaxies with central surface brightness fainter than 26 mag arcsec$^{-2}$ in the B band (Sabatini et al. 2003; Roberts et al. 2007). Mihos et al. (2005) obtained with the 0.6m Burrell Schmidt Telescope the deepest images yet available towards the most massive galaxies in the cluster, detecting new intracluster stellar streams and fine-structures (Janowiecki et al. 2010).

The Next Generation Virgo Cluster Survey (NGVS) aims to reach the sensitivity of the Burrell Survey, with excellent image quality over the full area of the VCC survey, and providing all the colors of the SDSS. When completed, it will be the reference database for any optical study on the Virgo Cluster. The NGVS is a Large Program of the 3.6m Canada-France-Hawaii-Telescope. It takes advantage of its excellent site (the summit of the Mauna Kea), the wide field of view and good spatial resolution of the MegaCam camera, and the large number of hours allocated to the project (771 hours distributed over 4 semesters between 2009 and 2012). More specifically, NGVS provides a contiguous coverage in 5 bands ($u,g,r,i,z$) of the Virgo cluster from its core to its virial radius. The 104 deg$^2$ survey area (about 8.6 Mpc$^2$ at the distance of Virgo) is tiled in 117 slightly overlapping MegaCam pointings.

2 Observational challenges

Viewed from the NGVS, Virgo looks amazingly different than the vision of the cluster seen in some previous imaging studies. Fig. 1 presents a composite image of one of the MegaCam fields. The cluster and its galaxies are hardly recognizable. The many features visible on this image are detailed below, ordered as a function of distance to the observer:

- instrumental signatures! MegaCam is a complex instrument hosting 36 individual CCD detectors and numerous optical elements. In order to minimize their imprints on the final stacked images, specific observing strategies and pipelines had to be implemented. A master sky is built and subtracted from all individual images before stacking them. The pipeline Elixir-LSB developed at CFHT by J.-C. Cuillandre performs the data reduction, optimized for the detection of low-surface brightness structures. It allowed the reduction of instrumental artifacts to a minimum: horizontal bands due to the lower sensitivity in the gaps between the CCDs are visible only when getting to 0.2% of the sky level.

- a myriad of white dots, most of which are faint foreground stars. Indeed, Virgo is located behind the so-called Virgo over-density, a particularly crowded region of the Milky Way halo where several stellar streams cross (Law et al. 2005). One of the aims of the NGVS is to study such streams which provide information about the formation of our own Galaxy. A fraction of the point-like sources are, in fact, intracluster globular clusters associated with Virgo galaxies. The study of their spatial distribution — see for instance the work by Lee et al. (2010) in the

\footnote{https://www.astrosci.ca/NGVS/Home.html}
Fig. 1. Composite image (u:blue, g:green, i:red) for one of the NGVS fields, on a logarithm intensity scale. The low-surface brightness features are emphasized, displaying the images at their limiting surface brightness (29 mag arcsec$^{-2}$ in the g-band).

SDSS — greatly facilitated by the high spatial resolution and depth of the NGVS, gives key information on the dark matter profiles of the massive cluster galaxies as well as on the intracluster stellar streams.

• camemberts crossed by spikes ... due to halos of bright foreground stars. The light around the most luminous stars contaminates the low-surface brightness structures in the image and has to be carefully subtracted.

• diffuse green/yellow extended emission as well as parallel narrow patterns (especially visible to the East) due to foreground cirrus clouds in the Milky Way.
Scattered emission from Galactic interstellar clouds and red emission associated with photoluminescence (Witt et al. 2008) can mimic stellar streams (Cortese et al. 2010). The detection of the intracluster light and remnants of past galactic collisions – one of the major goals of NGVS – must therefore contend with the presence of cirrus. Even though they cannot be eliminated, they may be identified using ancillary data, in particular, from their far-infrared and ultraviolet emission. NGVS will benefit from the availability of parallel Herschel HeViCS (Davies et al. 2010) and GALEX GUViCS Virgo surveys.

- A few white elliptical stains... the galaxies themselves. Some of them are located behind Virgo such as the colliding system with prominent tidal features to the North-East of the image. Of course, this background science is a key component of the CFHT Large Program: providing a deep, contiguous field over an area of more than 100 square degrees, the NGVS allows searches for distant clusters of galaxies and extends the weak lensing analysis started with the CFHTLS, one of the previous CFHT Large Programs dedicated to cosmology.

One of the challenges facing the Next Generation Virgo Cluster Survey is to identify — in the forest of foreground stars, Galactic clouds and background galaxies — objects that are actually located in the Virgo Cluster, in particular, the least massive ones that were discussed in depth during this conference. Our preliminary analysis, presented below, indicates that this is indeed feasible and that it might even be possible to identify in Virgo counterparts of the (ultra)-faint dwarfs so far detected only in the Local Group.

3 Dwarf galaxies in the NGVS

There is a long history of studies of dwarf galaxies in Virgo, addressing the possible evolutionary links between their various classes – dwarf ellipticals, with or without nuclei, irregulars, blue compact, ultra-compact (see for instance Lisker et al. in this volume) – the effect of the environment on their properties, or their scaling relation in connection with the more massive galaxies (Graham et al. in this volume; Côté et al. 2010, submitted). All these studies benefit from having a large sample of galaxies spanning the widest possible range in cluster-centric distance, such as that provided by the NGVS. The other playground of dwarf aficionados is the Local Group where recently a new population of so-called ultra-faint dwarf galaxies has recently been discovered, studied and, in some cases, claimed that they may (partly) solve the missing satellite problem in cosmology. The NGVS allows for an extension of the quest for the least massive galaxies to the distance of the Virgo Cluster.

3.1 Detection

The detection and photometry of the NGVS faint dwarfs raises a number of technical issues and require software developments.
As a first step in these efforts, we have identified by eye Virgo LSB dwarf candidates in multi-band images of the central 4 square degrees of the cluster. This exercise was carried out by three independent groups and the results were cross-matched.

In parallel, automatic pipelines are being developed. One code makes use of an optimized version of SExtractor run on ring-filtered images and the 2D profile fitting code Galfit (Peng et al. 2002). The second code benefits from the development of MARSIAA (MARkovian Software for Image Analysis in Astronomy) carried out at the Strasbourg University (Vollmer et al., 2010, submitted). This image segmentation software decomposes images into classes of pixels, each of these families being defined by a specific statistical behavior. One or several of these classes correspond to the LSB structure. MARSIAA processes simultaneously multi-band data images. An additional software, DetectLSB, digests the masks created by MARSIAA and identifies the LSB dwarfs (see further details in the poster contribution of Ferriere et al. in this volume). Each of these pipelines produces false-positive detections which should then be manually cleaned.
3.2 Preliminary results

The eye detection exercise performed in the central regions led to the detection of $\approx 550$ objects, the majority of which (about 360) were previously uncatalogued. Based on their sizes, colors and surface brightnesses, they have a strong likelihood of belonging to the cluster. Given their central surface brightness (up to 27 mag arcsec$^{-2}$ in the $g$-band), a spectroscopic confirmation is far beyond the capabilities of current facilities. Examples of true color images and surface brightness maps for three Virgo LSB dwarfs are displayed in Fig. 2. The absolute magnitude of the faintest one puts it close to the transition between dSphs and ultra-faint dwarfs in the Local Group. The NGVS detection rate in the core — about 140 objects per square degree — is at least three times that achieved by previous generations of deep surveys made towards specific strips of the Virgo cluster (Roberts et al. 2007). The census will be extended to the full cluster when the automatic detection pipelines are fully functional.

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