VISTA Extragalactic mini-survey: deep survey of the stellar halo in the nearby edge-on spiral galaxy NGC 253

1 VISTA science verification team

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2 Abstract

We propose a deep imaging survey in the Z and J broad bands, plus the NB118 narrow band of the edge-on nearby spiral galaxy NGC 253. We aim at detecting the faint Red Giant Branch (RGB) stars in the galaxy halo and in the stellar streams, detect and characterize the metallicities of the galaxy satellites in the field, plus the detection of globular clusters/ ultra compact dwarfs in the galaxy outer halo. The goal is to constrain the galaxy assembly history, and the underlying galaxy mass distribution for this nearby edge on-spiral galaxy. The deep narrow band imaging will complement the broad band- and the optical data for NGC 253 from the ESO science archive to map the opacity of the halo, as well as probe the star-formation rate at redshift 0.84. The total observing time requested for this project is 40 hrs, for the broad band and the narrow band exposures, including overheads and calibrations.

3 Scientific justification: Detecting the Red Giant Branch stars in the faint outer halo of NGC 253

Why NGC 253? – NGC 253 is a barred Sc galaxy seen nearly edge-on as in Fig. 1, in the Sculptor group at the distance of 3.9 Mpc, and it is one of the best nearby examples of nuclear starburst galaxy. Its coordinates are RA=00h47m33.1s DEC=-25d17m18s (J2000). During the VISTA SV run, from Oct. 15 to Oct. 30, 2009, this galaxy is observable for most of the night with airmass less than 1.5, and it can be observed before Orion (see the VISTA Galactic mini-survey in Orion). The deep image of Malin & Hadley (1997, PASA, 14 52) reaching 28 mag arcsec^{-2} shows the presence of an extended asymmetrical stellar halo plus a Southern spur. A very small portion of its stellar halo has been studied for distance determination, and the accurate distance (D=3.9 Mpc) to the galaxy has been determined by resolving and detecting the RGB tip stars in a halo field observed with the WFPC2 camera on board HST. A wealth of data is available in the ESO archive: narrow band Hα, and (shallower) broad bands from the ESO/MPI-2.2 WFI, and imaging and spectra of the nucleus with SOFI/ISAAC.

Detecting RGB in the diffuse stellar halo and streams in NGC 253 – The satellites of the Milky Way and M31 are mainly dwarf spheroidal galaxies (dSphs). These are located within 300 kpc from the MW, have central surface brightness in V band in the range 23-26 mag arcsec^{-2} (absolute integrated magnitudes in V from -8.5 to -13), and tidal radii of about 2 kpc. They are mostly old (11 Gyr) and metal poor ([Fe/H]= -1.7). For such a stellar population, the absolute magnitude at the tip of the RGB is at Z=-4.51 and J= -4.94, as computed using from Padova isochrones calculated for the UKIDSS photometric system, see Fig. 2. Extrapolating the above numbers to the distance of NGC 253 (distance modulus = 27.59 from Mouchine et al. 2005, ApJ, 633, 810) the apparent magnitudes at the tip of the RGB would be $m_Z = 23.3$ and $m_J = 22.9$.

Assuming a VISTA field of view of 1.5 deg x 1.0 deg (the area fully covered at least twice, when considering the instrument paw-print), this corresponds to 102 kpc×68 kpc at a distance of 3.9 Mpc. This FoV will allow us to detect the relatively smooth stellar halo within 20 kpc of the main spiral disk, the stellar streams like those detected in NGC 5907 and M31, and the nearby dwarf satellites like the Magellanic Clouds, Sculptor dSph, Carina, Ursa Minor, and Draco.

Resolving single stars with VISTA – Using the Sculptor dwarf spheroidal as template, for which there are $\sim$ 130 RGB stars within 1 magnitude below the tip of the RGB within 0.2 deg from the center, one estimates an average of 0.06 RGB stars per VISTA pixel (taking a pixel size of 0.339 arcsec, corresponding to 6.5 pc at 4 Mpc). For lower surface brightness dSphs, this number will be smaller. We conclude that RGB stars close to the tip can be resolved at a distance out to 4Mpc.

NGC 253 is at high Galactic latitude (-87.9) therefore the contamination from Galactic foreground stars is small.

Given the wide FoV of VISTA and its very good image resolution (0.5" PSF FWHM expected), we will also be able to perform a thorough census of massive compact stellar systems associated with NGC 253 and the intra-group medium. With a stable and well-defined PSF, intrinsic sizes of 3-5 pc will be resolvable. The census will be sensitive to analogs of Local Group objects like wCen / G1 with masses of a few million solar masses and sizes $r_h = 3 - 10$ pc, but also the more massive ultra-compact dwarf galaxies (UCDs). Those extend to masses up to 10^8 solar masses, and sizes up to $r_h = 100$ pc. Up to now, UCDs have been found mainly in the central regions of galaxy clusters, and it is unclear whether they exist in poorer group environments. The VISTA science verification data will allow significant advances in this respect.

About streams – Simulations from Bullock and Johnston 2005, Font et al. 2006-2007, predict that the inner haloes (≤ 20 kpc) of galaxies built in a hierarchical scenario should be relatively smooth, while the outer halo should present quite a variety of substructures. Of these, the highest surface brightness features (28-30 mag arcsec^{-2}) will be mostly due to single accretion events and are in general expected to be metal rich; the lower surface brightness features instead will be due to the accretion of many smaller units, which are supposed to be more metal poor. The metallicity/color of the brightest features should give some insight on the assembly history of galactic haloes, since the more metal poor the object, the earlier the accretion event. Our exposure times are computed so that both low and high metallicity streams can be detected.

4 Scientific justification: the map of the opacity of NGC 253 and the star formation rate at z=0.84

In addition to the broadband imaging, we propose to carry out a search for Hα emitters in the background of NGC 253 at a redshift of 0.84, using the NB118 narrow band filter. The purpose of this search is to map the opacity of NGC253 and its halo, as well as to probe the star formation rate at that redshift. Line emission objects will be identified by comparing the narrow band image with the corresponding broad band images. The vast majority of detected lines will be Hα.

A large enough sample of star-forming galaxies at that redshift can be used to test for foreground extinction using two different methods. First, the imprint of the extinction on the Hα luminosity function will reveal extinction from the narrow band images alone. The effect of the extinction will be to shift the number counts to fainter luminosity bins of the luminosity function

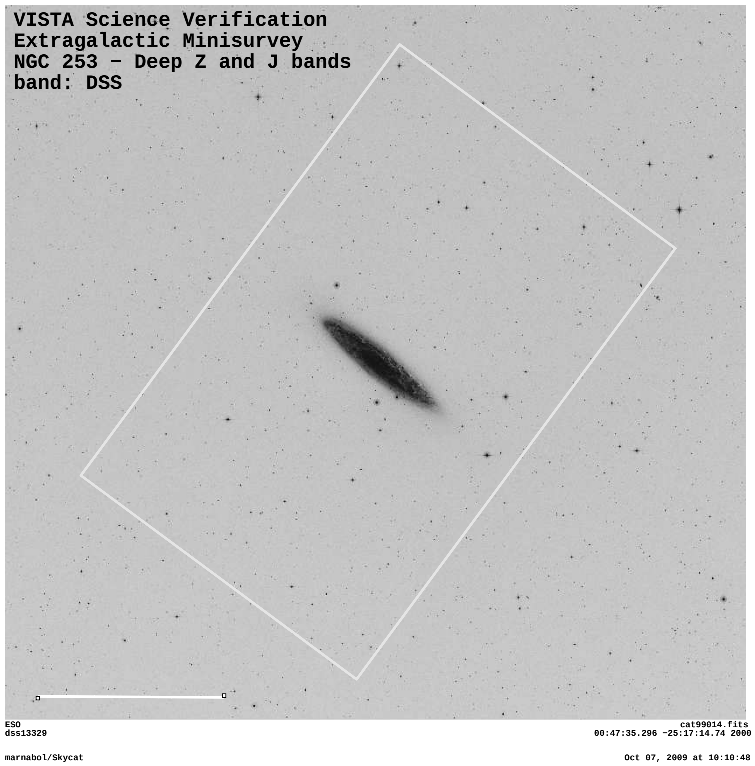

Figure 1: DSS image covering $2^\circ \times 2^\circ$ field centred on NGC 253. The VISTA field will be acquired with the camera rotator at PA $= 52^\circ$ so that the longer dimension of the image is aligned with the galaxy minor axis, as shown in the figure. In the MW galaxy, most of the dwarf satellites are found along the MW polar plane: if this is also the case in NGC 253, the pointing and the adopted PA of the camera will allow us to survey ~ 110 kpc along its meridian plane.

(e.g. Villar et al. 2008, AJ 677, 169), an effect which can easily be recognized. The second method is to investigate variations in the broadband surface brightness of the Hα selected sample as a function of position and color. The surface brightness of star-forming galaxies sharply peaks (e.g. Brinchmann et al., 2004, MNRAS 351, 1151) and the position of this peak as a function of position can be used to identify high extinction regions.

In order for both of these methods to work, the number density of detected $H\alpha$ emitters has to be large enough to allow determination of the luminosity function and surface density distribution on a sufficiently fine position grid. For the luminosity function, we need to reach a depth at least a factor of 100 fainter than L($H\alpha$). Typical measured values for log(L($H\alpha$) [erg/sec]) are about 42 to 43. We conclude that we need to reach a sensitivity of about log(L($H\alpha$) [erg/sec])$\approx$ 40.5, which corresponds to a star-formation rate of about 0.5 $M_{\odot}/yr$. Villar et al (2008) detect about 900 $H\alpha$ emitters per square degrees, reaching a sensitivity of log(L($H\alpha$) [erg/sec])$\approx$ 41. Extrapolating their luminosity function, we estimate that there are about 2500 Hα emitters per VISTA tile brighter than our proposed luminosity limit. Such a sample is large enough to allow the determination of the luminosity function for subsamples, and thereby enable us to map the opacity as a function of position within the foreground galaxy. Similarly, the sample is large enough to determine variations of the peak of the surface brightness distribution with an estimated sensitivity of about 0.1 magnitudes. This sample of 2500 Hα emitters will also be the largest sample to date at that redshift, and we will be able to use it to determine the most accurate star formation rate density for that epoch.

Extent of dust disk around spirals – The extent of the dust halo/dusty disk around spiral galaxies is - except for very few studies - largely unknown. By observing a nearby edge-on galaxy optically and in the NIR, an extinction map around the galaxy can be made by studying the colors of background objects as a function of distance from the disk. This could help to constrain the total dust mass of spiral galaxies and possibly provide information on galactic winds. Hence choosing a galaxy that already has wide-field optical imaging may increase the science that can be done with the VISTA science verification extragalactic data.

5 Scientific justification: Mapping the disk and bulge structures of NGC 253 with shallow exposures

Complementary to the deep J and Z exposures we will also obtain shallow Y, J, H, K_s images of NGC 253. These exposures have been tuned such that the brightest components of NGC 253 do not reach the linearity limits of the detectors (as they will for the deep J-band exposures).

Most of what we know about the structure, evolution and dynamics of stellar populations, and their connection to dark matter, is deduced from high surface brightness features: bars, bulges, and thin disks. Fainter surface brightness components such as stellar halos, thick disks, and globular clusters probe galactic potentials differently, in both time and space owing to their larger age and extent. The formation mechanisms of these faint tracers are still a matter of some controversy; suggestions range from early protogalactic collapse, secular processes such as heating from molecular clouds, black holes and spiral structure, through to later stochastic processes such as accretion (see the reviews by Buser, R. 2000, Science, 287, 69; Bland-Hawthorn, J. & Freeman, K., 2000, Science, 287, 79; and references therein). These scenarios predict different kinematical, morphological and chemical characteristics, but too few systems have been sufficiently well studied to constrain the models.

The primary goal of this shallow survey will be to model the disk and bulge components of NGC 253 and, together with the deep imaging data, detect any signatures of an extended thick disk component. With the addition of optical data obtained from WFI, along with a reliable bulge/disk decomposition we can estimate the mass via luminosity and a colour-based mass-to-light ratio. Both the disk model and the large number of observed wavebands will be used to search for possible streamers in the disk and halo of NGC 253.

Finally, because the shallow survey has been designed to include off-source sky images placed between the observations of NGC 253, we will be be able to provide an accurate photometric solution in all of the observed bands. This will be used as a photometric boot-strap for the deep survey.

6 Exposure time and observing strategy

Our plan is to image a single field centred on NGC 253 in two broad band filters, Z and J, plus the narrow band, NB118. We are planning to rotate the camera to $PA = 52^\circ$ so that the longer axis of the camera is aligned with

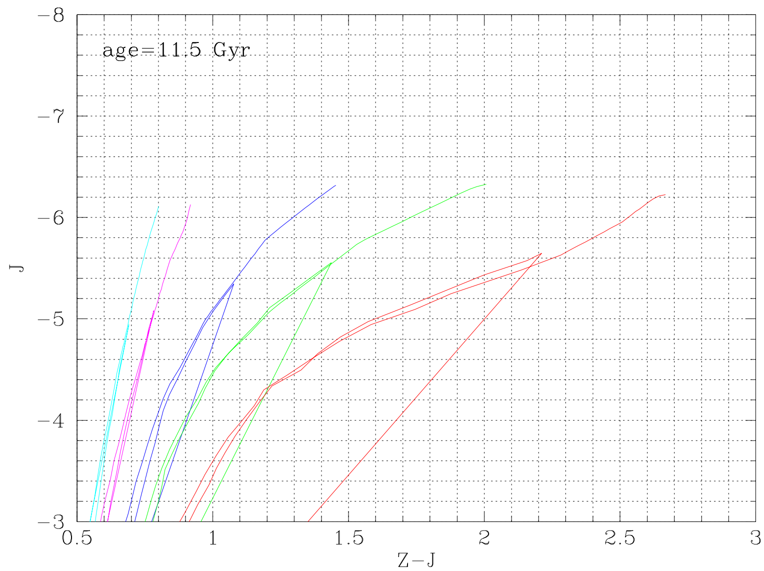

Figure 2: The Padova isochrones for the 11 Gyr populations and for Z=0.0004, 0.001, 0.004, 0.008, and solar metallicity for the Z and J filters from the UKIDSS photometric system (which is similar to VISTA). The metal-poor isochrones have bluer colors. The brightest point of these isochrones corresponds to the end of the AGB phase. The RGB tip is at the J=-5 for the most metal poor, and at -5.6 for the most metal rich isochrone. The relatively wide range of colors covered by this combination of filters gives the best compromise between the transmission and the metallicity sensitivity for all the available filters.

the galaxy minor axis and allows to cover about 110 kpc along the galaxy meridian plane.

The shallow survey geometry consists of three fields, two on-source and one on-sky, all of which are rotated along the major axis of NGC 253. For each filter the following strategy will be followed: The first object exposure is centered on NGC 253 and uses the VIRCAM tile pattern *tile3px*. The subsequent exposure is located 2° to the northwest of the source and consists of a single tile (*tile1_00*) of equivalent exposure time on sky. The final OB returns to the source, offset by the size of the vertical detector gap and fills in the galaxy coverage using the *tile3nx* pattern. To ensure good sky characterization, these three OBs must be executed consecutively. As such, they are contained in a p2pp concatenation. The order of filter preference is J, K, H, and Y. The Z-band will be taken by the deep survey.

Broad bands - Table 1 indicates the absolute and apparent magnitude of

Band	Abs. magnitude at RGB tip	App. magnitude at RGB tip	N_{obs}	Tot Exp. time	S/N (seeing = 0.8″)	S/N (seeing = 1.0″)
Z (MR)	−4.76	23.0	2	3.2h	10	8
Z (MP)	−4.51	23.3	4	6.3h	10	9
J (MR)	−5.65	22.1	4	5.9h	10	8.5
J (MP)	−4.94	22.9	15	22.1h	10	8

Table 1: Table of exposure times in band Z and J at magnitudes corresponding to the tip of the red giant branch for an old stellar population (11 Gyr) of solar metallicity (case MR) or metallicity [Fe/H]−1.7 (MP), placed at the distance of NGC 253 (distance modulus 27.59 from Mouhcine et al. 2005, ApJ, 633, 810). The apparent magnitudes include the reddenings, which are $A_Z = 0.0.036$ and $A_J = 0.017$ in the line-of-sight of NGC 253. We have used the VISTA ETC (http://www.ast.cam.ac.uk/vdfs/etc/index.html) with the following parameters: blackbody of T=5000 K; airmass = 1.5; sky magnitudes = default. N_{obs} and Exp. time are the number of exposures and the corresponding exposure time, respectively, needed to reach a S/N=10 with a seeing = 0.8″. The S/N we would obtain with the same N_{obs} and Exp. time but seeing = 1.0″ is listed in the last column. The observing strategy is summarized in Table 2.

Band	DIT	N_{dit}	N_{jit}	N_{paw}
Z	60	3	5	6
J	35	6	4	6

Table 2: Observing strategy parameters.

the RGB tip in Z and J for different metallicites, the exposure times, and the S/N reached as function of seeing. Table 2 lists the parameter for the observing strategy. The total execution time for the broad band imaging in Z and J is of ~ 30 hrs, according to the VISTA exposure time calculator

Narrow bands - The necessary sensitivity to reach log(L($H\alpha$) [erg/sec])$\approx$ 41 is about 5×10^{-16} erg/sec/cm^2. To estimate the required exposure time, we used the ETC with the almost identical parameters as for the broad band observations. The only difference is that we used 5 arcsec apertures to account for the size of the galaxies. We found we need a total exposure time per tile of 5 hours, or 6 hours including overheads as given by the ETC.

Plus overheads and calibrations (standard stars fields for the broad band, spectrophotometric standard stars for the narrow band), we request 40 hrs total for this project.