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Future prospects for AGN and galaxy surveys with the LBT Large Binocular Camera

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Abstract. The Large Binocular Camera (LBC) is a wide field of view instrument at the prime focus of the twin 8.4 meter Large Binocular Telescope. The Blue channel of LBC has been already installed at the telescope and the first light images have been successfully obtained on October 12th, 2005. LBC is able to provide faint images of the sky down to the level of the Hubble Deep Fields, but in an area that is 150 times larger. A number of high-quality scientific programs requiring extremely deep images in the near UV wavelength are highlighted, which become feasible with this powerful instrument.

Key words. Instrumentation: detectors – Telescopes – Surveys – quasars: general – Galaxies: high-redshift – Cosmology: observations

1. Introduction

The recent epochs are witnessing a very active phase for observational cosmology. Detailed analyses of the physical properties for galaxies and AGNs are boosted by surveys covering areas comparable to the whole sky, like the Sloan Digital Sky Survey [SDSS, Abazajian et al. (2005)] or small portion of the sky down to faint magnitude limits, like the Hubble Ultra Deep Field [HUDF, Beckwith et al. (2003)]. In the epoch of 8-10 meter class telescopes, the combination of large Field of View (FoV) and deep areas has become feasible and is strongly required by present day extragalactic surveys. Both wide and deep imaging in the UV-optical-NIR will large benefit in the near future from the Large Binocular Camera (LBC), which is briefly described here.

In § 2 I summarize the main motivation for building the LBC instrument, I describe its main features and compare it with similar instrumentation. I discuss the performances of LBC on the basis of extensive simulations and the first light results in § 3. In § 4 I enumerate future prospects for AGN and galaxy surveys with LBC, focusing in particular onto simple but effective topics.

2. The Large Binocular Camera

2.1. The motivations for LBC

The need for an instrument like LBC is outlined by several high-profile scientific programs which call for an increase of the FoV and for high UV-IR sensitivity for deep imaging, which can only be provided by an imager at the prime focus of an 8m class telescope.

The concept of the LBC camera started in 1997 under a detailed scientific case from

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the Italian community. There was a need for deep wide field imaging, which is still actual today. Main scientific topics which can effectively benefit by the LBC instrument goes from the search of faint asteroids to the statistical properties of distant galaxies, in particular minor planets or near earth objects in the solar system, primary distance indicators, faint stellar populations, novae and supernovae, intracluster planetary nebulae, radio galaxies and faint QSOs.

The main motivation of the LBC project is the need of a wide field imager efficient especially in the UV, where even in the HDF is evident the dramatic inefficiency of present day instrumentation (see Fig. 5).

2.2. Description of the instrument

The Large Binocular Telescope (LBT)[1] is a binocular telescope consisting of two 8.4-meter mirrors on a common mount (Hill et al. 2000), located at the Mt. Graham International Observatory near Safford, Arizona. The first-light LBT instrument (Fig.1) is the Large Binocular Camera[2] (Ragazzoni et al. 2000; Pedichini et al. 2003), a prime focus imager of 24 x 24 *arcmin*^{2} FoV. The main technical challenge for the LBC instrument is the complicated optical path to reach the prime focus, which is solved with a corrector made up of 6 lenses made of fused silica set in front of the CCD array. It is needed to correct the comatic aberration of the fast primary mirror to make an extended field-of-view. The first and major lens is 80 centimeters of diameter and is shown in Fig. 2.

LBC is a wide FoV (1/6 of *deg*^{2}) instrument for deep imaging at the prime focus of the LBT telescope. The LBC instrument has two channels: the Blue channel (LBC BLUE) optimized for the UV imaging (U, B and V bands) while the Red channel (LBC RED) represents an optimal solution for Near Infrared Imaging (V, R, I and Gunn-z) with a red-optimized and thick CCD to avoid fringing. In the full binocular configuration indeed, both channels will be available simultaneously, both pointing in the same direction of the sky. This allows to double the net efficiency of LBT.

Each CCD array is composed of 4 EEV chips (2048 x 4608), on both channels, to obtain an equivalent 6150 $\times$ 6650 pixels detector, without including the pre- and over-scan (256 pixels) and the gap between the CCDs.

Fig. 1. The blue channel of LBC at the prime focus of the Large Binocular Telescope.

Fig. 2. The big lens is part of the corrector, a special device to concentrate the light of LBT at the prime focus of the wide field imager LBC.

[1] http://medusa.as.arizona.edu/lbtwww/lbt.html
[2] http://lbc.mporzio.astro.it/

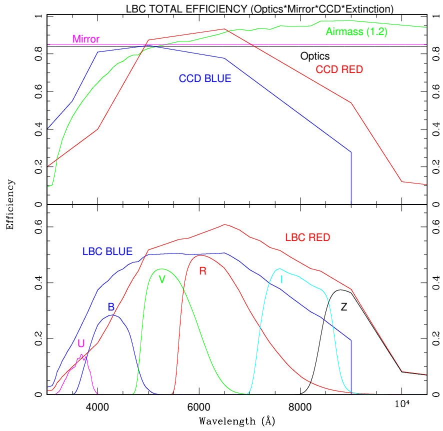

Fig. 3. The total efficiency of the two channels for the LBC instrument. The total efficiency is the product of the reflectivity of the mirror, the transmission of the optics, the quantum efficiency of the detectors/CCDs and the extinction due to the atmospheric absorption (airmass=1.2). CCD BLUE and CCD RED represent the two detectors, optimized for UV (UBV) and NIR (VRIz) imaging. The filter curves are the result of the product of the total efficiency of the instrument by the absolute efficiency of the filters.

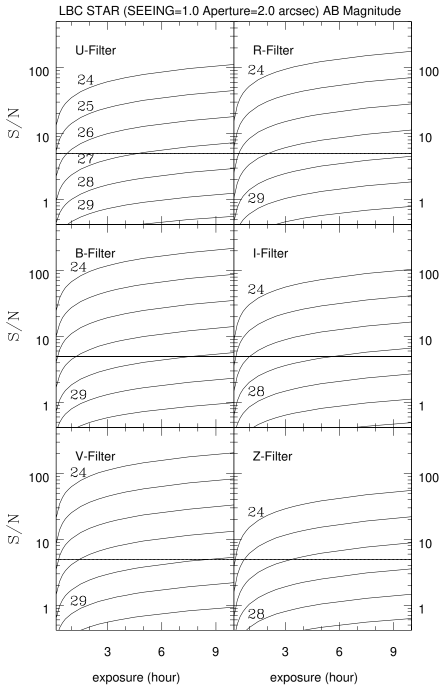

Fig. 4. Signal to Noise ratio as a function of exposure time for stars in U,B,V,R,I,Z bands, predicted by the LBCSIM. Elliptical galaxies reach the same S/N if the magnitude is 0.35 brighter, while for spiral galaxies the difference is 0.2 magnitudes.

The four chips are placed in a rather unconventional fashion, with the fourth one rotated by 90° with respect to the other (see Fig. 7), to cover the corrected FoV in an optimal way. Pixel size is chosen to be 13.5 μm (corresponding to 0.24 arcsec) allowing for a fine sampling in case of good seeing. UV coated thinned EEV types for the blue channel and IR coated thick EEV for the red channel have been chosen for the camera, with a very low expected fringing, which usually affects observation in the I and Gunn-z bands. The expected quantum efficiency (QE) of the two CCDs (as provided by EEV) is shown in Fig. 3, together with the reflectivity of the mirror, the transmission of the atmosphere (for an airmass of 1.2) and the corrector (optics).

2.3. LBC main features

It is useful to stress here that LBC is not a simple wide field imager, whose type of instrument is quite common in astronomy, but it is a prime focus imager at an 8m class telescope, particularly efficient in the UV wavelengths. Thus, LBC is a competitive instrument, but competitors are already on-line. For example, the Suprimecam at the Subaru telescope, in operation since two years, is a wide field imager at the prime focus of an 8m telescope but cannot observe in the U band. For comparison, LBC has the advantage of an efficient UV window, short read-out time and larger, effective FoV. As a disadvantage, with LBC it is not possible to use narrow band filters, due to the optical design of the camera. Another competitor

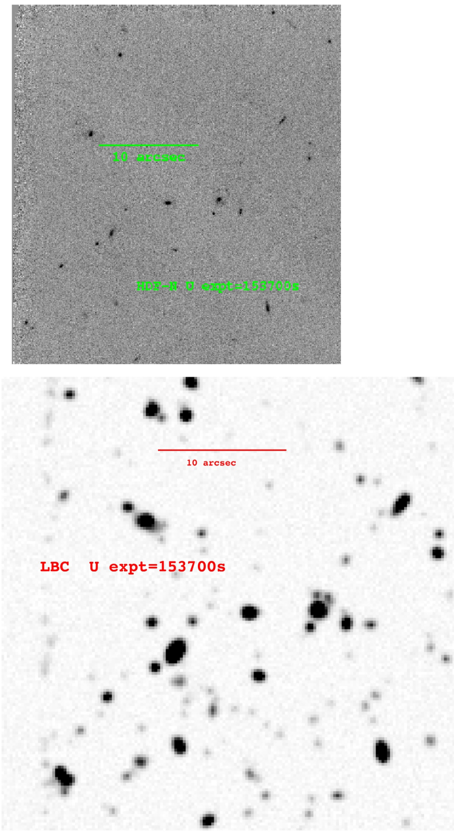

Fig. 5. A sub-set of the HDFN in the F300W band, showing particulars of faint sources (up). The same sub-field as might be seen by LBC instrument (down). The spatial resolution of the LBC image is lower than that of HDFN, but the faint sources have a comparable Signal to Noise ratio for detection.

is Omegacam at the MMT telescope. Its main characteristics are similar to Suprimecam, and compared to LBC, it is less efficient in the UV and has a smaller FoV. The main advantages of LBC are indeed clear, making it a highly competitive instrument. The UV channel is the main feature of LBC, which is complementary also to the present capabilities of ACS and to future space missions like JWST.

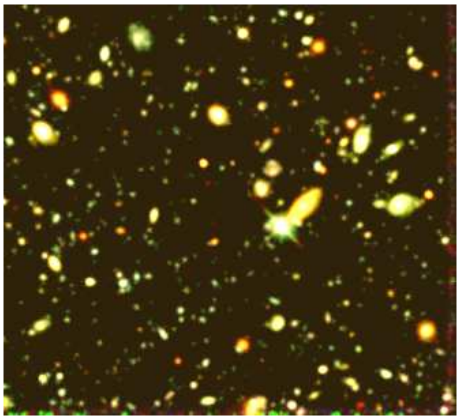

Fig. 6. Color image of the HDFN with LBC resulting of a composition of deep U, V and I band images. Each band corresponds to a simulation with an exposure time of approximatively 30 hours.

3. LBC Performances

3.1. Simulations

In this section the expected performances of the LBC camera are derived, by means of the LBCSIM image simulator software (Grazian et al. 2004). LBCSIM introduces the instrumental effects and gives the characteristic shape of LBC camera, as well. We investigate first the limiting magnitudes of LBC, for different type of sources (star, elliptical and spiral galaxy) in various standard filters. To make realistic simulations, we have used the WFPC2 observations of the HDFN as input images for LBCSIM. Simulated images for LBC have been produced in several bands and for different exposure times, and analyzed using the standard software SExtractor (Bertin & Arnouts 1996). The aim of this exercise is to estimate the performances of LBC when the clustering, morphology and colors of real astronomical objects are taken into account. Finally, we show the expected performances of LBC to produce deep imaging survey.

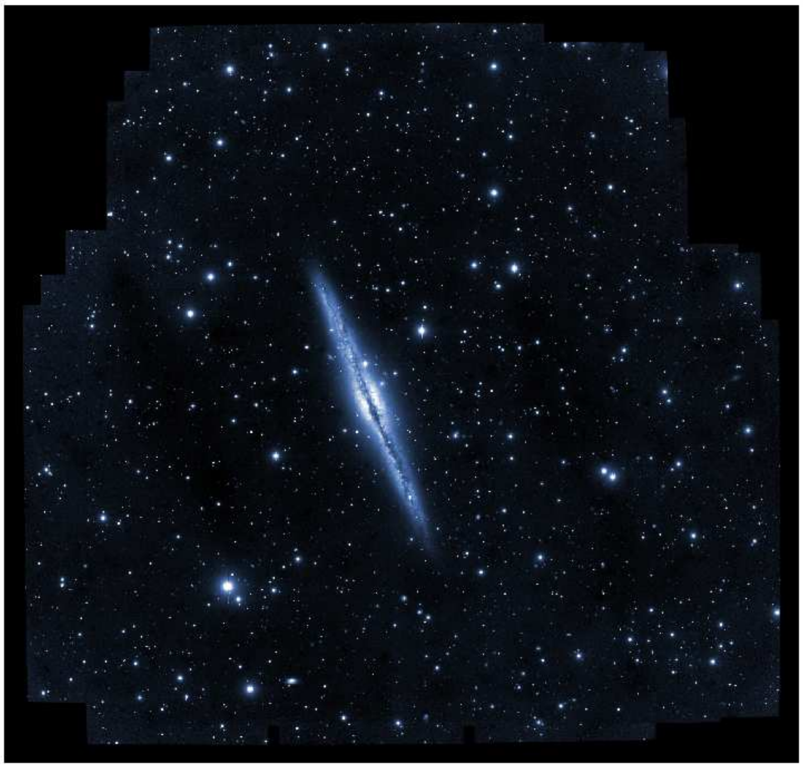

Fig. 7. LBT "First Light" image of the galaxy NGC891 taken on October 12th, 2005. The galaxy NGC891 as seen by the blue channel of LBC at its first light. The image is taken in the B band, with an exposure of 5 minutes in total and with a typical seeing of 0.8 arcsec. The FoV is 30 by 30 square arcminutes, similar to the angular size of the full moon. There are numerous smaller and more distant galaxies in the background of the NGC891 field. These are more typical of what a large telescope like LBT will study.

3.2. Magnitude limits for LBC

To show the performances of LBC in details, we study the magnitude limits in different bands with the LBC simulator for different conditions of seeing. Fig. 4 shows the Signal to Noise ratio (S/N) as a function of exposure time for different filters of LBC for a stellar source at 1.0 arcsec seeing. The S/N is calculated in an aperture 2 times larger than the seeing. The other parameters are fixed to Moon=Dark and airmass=1.2. For an elliptical galaxy the expected S/N is lower than for a star of the same magnitude and it reaches the same S/N if the galaxy is 0.35 magnitude brighter. For a spiral galaxies, the magnitude difference to reach the same S/N of a star is 0.20 magnitude. With 0.6 arcsec seeing and a photometric aperture of 1.2 arcsec, the same S/N is obtained for fainter objects of 0.55, 0.37 and 0.25 magnitude for stars, ellipticals and spirals, respectively. Both the elliptical and the spiral galaxies have an half light radius of 0.4 arcsec, that is an upper limit for relatively faint galaxies observed in the HDFs (Windhorst et al. 2002) and it is used for a conservative estimation of the expected S/N for faint galaxies.

3.3. Simulations of Deep Fields with LBC

As an example of the LBCSIM typical application, we have used the images of the HDFN in the F300W, F450W, F606W and F814W filters. The background subtracted images are used as input frames for the LBCSIM software and simulated images of the same field seen by LBC are produced. The exposure times of the simulated images are the same of the original HDFN data. Table 1 summarizes the exposure times and the magnitude limits at 90% completeness of the HDFN and LBC simulated fields. The parameters used to generate the simulated images are: *seeing* = 0.6, *airmass* = 1.2 and *moon* = *Dark*. The magnitude limits for HST data are calculated in apertures of 0.28 arcsec (two times the PSF of HDFN) and 1.2 arcsec. For point like sources WFPC2@HST is able to reach a comparable magnitude limit in U and B and one magnitude deeper than LBC in the V and I bands for small apertures. *For extended objects like galaxies larger apertures must be used and the magnitude limits for LBC are 1.2 deeper than those of HST in the U and B and 0.6 deeper for the V and I bands, respectively.* In the B band LBC is as efficient as HST, in the case of point like sources, because of the low sky background and the high throughput of the instrument.

Fig. 5 (up) shows a sub-set of the HDFN in the U (F300W) band, to be compared with Fig. 5 (down) of the same sub-field as it will be seen by LBC with the same exposure time. Though the morphological informations are very detailed on space based images, not affected by the atmospheric turbulence, the collecting power of LBT makes the ground based images more suitable to the detection of faint sources. In particular, Fig. 5 (down) shows objects as faint as the magnitude limit of the F300W HDF field. Note that the U filter used for this simulation is the Bessel-U with low peak efficiency. If a special filter is available, similar to the one used by Steidel et al. (2003), LBC is able to detect much fainter sources. To obtain this image we take the HDFN field in the F450W band, dim the sources assuming a typical color of $U - B = 1.0$ and use it as input image for the simulation of a deep U band survey with LBC. Sources fainter than the HDF in the F300W band can be seen in the image. It shows clearly the power of LBC instrument to produce *deep imaging map of the sky on an area that is 150 times wider than the HDF*.

Fig. 5 is an application of the image simulator to study the potentiality of LBC in the field of deep imaging surveys. It is easy to show that LBC will reach HDF level in a much shorter time interval, especially in the U band.

Fig. 6 shows the HDFN field color image that is the composition of deep U, V and I deep images with LBC. The exposure times are chosen as deep as the HDFN and are 153700, 109050 and 123600 seconds for the U, V, and I, respectively. Fig. 6 is the result of a simulation for a total of ~ 100 hours at LBC.

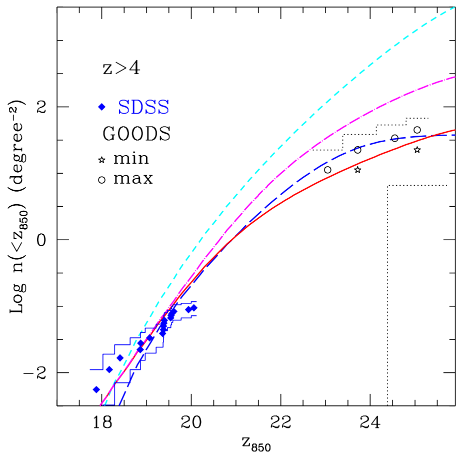

Fig. 8. Comparison of the observed QSO counts distribution with model predictions of two phenomenological and two physically motivated models. The counts are derived from the SDSS below $z_{850} \simeq 20$ and from Cristiani et al. (2004) above $z_{850} = 22.45$. Circles and stars show the "maximal" and "minimal" estimates of the GOODS counts, respectively. The dotted segments show the corresponding 1 σ upper (maximal case) and lower (minimal case) confidence limits. Models are represented by smooth lines for pure luminosity evolution, pure density and mixed evolution.

Table 1. The performances of LBC compared with the HDFN.

Filter	t_{exp} (s)	N_{dit} (HDFN)	N_{dit} (LBC)	HDFN (2*PSF)	LBC (2*PSF)	HDFN (1.2 arcsec)	LBC (1.2 arcsec)
U (f300)	153700	77	45	29.105	28.827	27.561	28.827
B (f450)	120600	58	180	29.397	29.476	28.344	29.476
V (f606)	109050	103	350	30.327	29.351	28.790	29.351
I (f814)	123600	58	600	29.742	28.714	28.207	28.714

The exposure time is in seconds, the magnitude are in the AB system (Oke 1974) and at a Signal to Noise ratio of 5. The N_{dit} parameter is the number of dithering carried out by HST and foreseen for LBC in order to minimize the background.

3.4. First Light Results

The "First Light" image at LBT (see Fig. 7) was obtained on the night of 12 October 2005. The target was an edge-on spiral galaxy (type Sb) in the constellation of Andromeda known as NGC891, which lies at a distance of 24 million light years. The galaxy M51 and the globular cluster M13 were chosen as other targets, as well. NGC891 is of particular scientific interest because the galaxy-wide burst of star formation inferred from X-ray emission is stirring up the gas and dust in its disk, resulting in filaments of obscuring dust extending vertically for hundreds of light-years.

4. Possible science case

4.1. Deep imaging for galaxies

Deep imaging in the near UV wavelengths is particularly important for extragalactic surveys with the aim of studying distant galaxies. Detailed information on the spectral energy distribution of galaxies or AGN gives precise parameters, like the photometric redshifts, masses, Star Formation Rate. Galaxies in UV, indeed, are extremely faint, and to detect them in the blue bands, extremely deep imaging is required (29-30 magnitudes in the AB system) to avoid having only upper limits in the UV part of the spectrum.

Thanks to its unprecedented efficiency in the UV wavelengths, LBC will bring an essential improvement in the field of extragalactic astronomy. In particular, the main scientific aims of LBC are, between the more interesting, the faint side of galaxy formation at $z \geq 3$, the escape fraction from galaxies at high redshift and the Large Scale Structures of the Universe at high redshift. Additional scientific drivers are: a relatively deep survey on 1-2 sq.deg. to select a large sample of galaxies till z=6-7, the study the clustering at $z \geq 3$, the search for LBGs and the analysis of the Luminosity Function by spectral type, beating also the cosmic variance problem. Finally a shallow survey on several sq. deg. will help in finding rare objects, like high-z clusters, Low Surface Brightness galaxies, QSOs or other serendipitous discovery.

Going into the details, large and deep areas are essential to study the clustering of galaxies over large scale, to find extended structures at high-z and to search for $z \geq 5$ galaxies with intermediate band filters. In particular, future photometric redshift surveys with LBC can put stringent constraints on dark energy equation of state through the baryon oscillations of the power spectrum (Amendola, Quercellini & Giallongo 2005). A fundamental feature of LBC will be the synergy with other ground or space-based instruments, like HST, Spitzer, GALEX, Keck, to complement the already available multi-wavelength imaging with deep observations in the UV, which is still lacking for major surveys like GOODS, COSMOS, SWIRE.

4.2. A survey of high-z QSOs

The study of faint QSOs at $z \geq 3$ will largely benefit from the combination of large area detectors and deep imaging available with LBC. Recently, a large number of distant QSOs has been provided by the SDSS (Schneider et al. 2005), at relatively bright magnitude limits. Cristiani et al. (2004) indeed, have produced a limited sample of faint QSOs at $z \geq 4$ in the GOODS regions, combining deep optical and X-ray data (see also the contributions from S. Cristiani and P. Monaco in this Volume for details). LBC is ideally suited to complement these two surveys and to cover the gap on the luminosity function at $z \geq 4$ (see fig. 8), where large areas are required in order to give constraints on the faint part of the QSO LF.

The measure of the correlation length of QSO Two Point Correlation Function at $z \geq 3$ is hampered by the low surface density of QSOs in the SDSS, where QSOs are rare and bright, or by the small number found in deep surveys like GOODS, which is limited in area. A large sample of faint QSOs over a connected and extended area of sky (5-10 sq. deg.) with LBC is particularly important to study the clustering of QSOs at high-z.

5. Conclusions

The LBC camera is a very efficient instrument for surveys. The enhanced transmission both in the UV and at redder wavelengths provided by the different channels (LBC Blue and Red) makes LBC a competitive imager, in terms of depth and multicolor efficiency in a large FoV: it will study galaxies as faint as those found in the HDFs but in an area that is 150 times larger. Competitors of LBC are already on-line, but its unprecedented efficiency in the UV bands will be unrivaled for the next years to come. Large benefit for AGN and galaxy science will result from LBC large and deep surveys, especially at high redshifts.

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