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# NIR/Optical observations of the GOODS-S field

## Tracing the mass assembly history of galaxies

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**Abstract.** The GOODS Survey (Great Observatory Origin Deep Survey) is providing unprecedented valuable data in the optical-NIR bands to investigate galaxies up to the extreme redshifts ($z \sim 7$) over a relatively large area of the sky. The survey is the result of a combined effort of space observatories (HST, Spitzer) as well as ground based telescopes (Keck, VLT). Using this public dataset, and focusing in particular on the VLT data in the Chandra Deep Field South region, we have produced a high quality multicolor catalog (from the U to the Ks band) for ∼14000 galaxies over an area of 135 sq. arcmin, complete to both $Z(AB) = 26$ and $Ks(AB) = 24$ magnitudes. To optimally match the HST high resolution images with the ground-based ones, we have designed a software for high precision photometry (*ConvPhot*) and an SQL database to manage properly this Multi Wavelength Catalog. This survey will give a uniquely comprehensive history of galaxies, from early epochs to the relatively recent past: at this purpose, we are focusing the attention on the Distant Red Galaxy (DRG) population at $z \sim 1-3$ to shed light on their still unclear nature and to avoid cosmic variance thanks to the large and deep area investigated. We will finally discuss how this work is useful to prepare future surveys with the LBC instrument at the LBT telescope.

**Key words.** Galaxies:distances and redshift - Galaxies: evolution - Galaxies: high redshift - Galaxies: photometry

## 1. Introduction

The Great Observatories Origin Survey (GOODS, PI M. Dickinson) represents the next generation of deep imaging surveys. Over a total area that is about 50 times the combined HDFN/S, it is the result of an impressive observational effort with the most advanced facilities, starting from the homonym Spitzer Legacy Program. The available dataset includes ultra-deep images from ACS on HST, from the mid–IR satellite SPITZER, the ultraviolet satellite GALEX, the X-ray satellites Chandra and XMM, as well as from a long number of ground–based facilities (see Giavalisco et al. (2004) for a more detailed presentation). Spectroscopic follow–up is also available or undergoing from a list of surveys

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and facilities (Cowie et al. 2004; Mignoli et al. 2005; Vanzella et al. 2005).

A high-quality Multi-wavelength catalog (MWC) has been produced using this public dataset at the Astronomical Observatory of Rome (AOR), on the basis of our previous experience developed within K20 and HDFS surveys. The scientific motivations are manifold: first of all, the wide spatial and spectral coverage of the GOODS field ensures an ideal dataset to study the formation and evolution of galaxies through the analysis of Luminosity, Mass functions and clustering properties till the highest available redshifts ($z \sim 7$). With the Spitzer data in the MIR, indeed, it is possible to investigate the rest frame K-band till $z \sim 3$, which allows to derive precisely the stellar mass in galaxies. The GOODS survey is fundamental to understand the role of stars and AGN in the energetic output of galaxies. The large volume sampled is useful to lower down biases due to cosmic variance, but still not sufficient to eliminate them totally.

Not least, the GOODS data represent an innovative challenge for detailed data analysis, due to the large amount and complexity of the imaging dataset. We have dedicated a combined effort for software developing and scientific analysis applied to a public dataset, with the aim to build an important expertise in the field of multi wavelength imaging surveys. GOODS is the prototype of future wide and deep surveys: it is an ideal dataset to test smart software tools dealing with data coming from different telescopes and of very dishomogeneous quality.

## 2. The Data

The GOODS southern pointing, located over the Chandra Deep Field South and encompassing the ACS Ultra Deep Field and the GMASS ESO Large Program (Galaxy Mass Assembly ultra-deep Spectroscopic Survey, PI Cimatti), has been the target of extensive observations with ESO telescopes, carried on in the spirit of public surveys. To date, the major effort has been devoted to deep imaging observations in the $J$, $H$ and $Ks$ bands with the VLT-ISAAC infrared imager. The final area covered by the

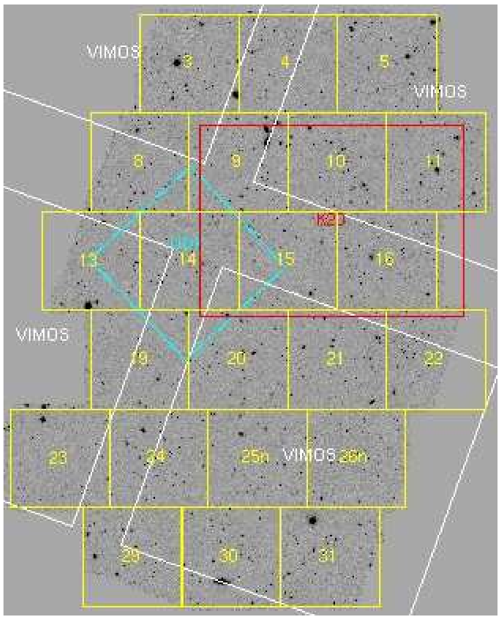


**Fig. 1.** The ACS GOODS-S field with the ISAAC tiling made by ESO to cover in J and Ks the whole field. The cyan square marks the position of the ACS UDF. The red rectangle marks the position of the K20 survey. The four white quadrants show the actual coverage of VLT-VIMOS U band imaging; large gaps are visible, since the observing program is just started.

$Ks$ images approaches 135 arcmin$^2$ to a $1\sigma$ limiting depth of typically 25-26 mag/arcmin$^2$ (AB), making it an unique combination of depth and size in the near–IR. We have included in our analysis the $b$, $v$, $i$ and $z$ ACS images, the Spitzer data provided by IRAC instrument (3.6, 4.5, 5.8 and 8.0 $\mu m$) and publicly available U–band data from the 2.2ESO ($U_{35}$ and $U_{38}$) and VLT-VIMOS ($U_{VIMOS}$), as shown in Fig. 1. The complexity of these data is not trivial: the magnitude limits, the pixel size and the resolution of the various images are heterogeneous, going from 24 to 30 mag, from 0.03 to 0.6 arcsec/px and from 0.1 to 2.0 arcsec, respectively. Indeed the ISAAC imaging has a different seeing from tile to tile, a further complication for the detailed photometric analysis of these data.

Objects in the GOODS field have been detected in the $z$-band with the SExtractor software. Detailed analysis of the complex RMS pattern of the detection image, together with simulations of synthetic galaxies of different size (half light radii) and magnitude, indicates that the completeness limit at $10\sigma$ is $z = 26.2$ (AB) in the deeper part of the image. The shallower area is complete down to $z = 25.7$. A more detailed analysis of the completeness and coverage of the GOODS-South is provided in Grazian et al. (2005).

To estimate galaxy colors of detected objects one needs to distinguish different situations:

- For $b$, $v$ and $i$ bands of ACS, where the PSF is similar to that of $z$ band, we used SExtractor in dual image mode and $MAG\_BEST$ estimator.
- For $J$, $H$ and $Ks$ bands of ISAAC we used the *ConvPhot* software (De Santis et al. 2005), a profile matching algorithm for precision photometry written at this purpose. We used the $z$ band as model image and derived the photometry in each ISAAC field with the appropriate PSF profile.
- For the $U_{35}$, $U_{38}$ and $U_{VIMOS}$ bands, we used *ConvPhot* with the $b$ band as model image to minimize changing of galaxy morphology with wavelength.
- For IRAC bands (from 3.6 to 8$\mu$m) we used *ConvPhot* with the $z$ band as model image. There are two important caveats: the PSF variation across the large field and different morphologies between $z$ and IRAC bands.

A precise description of the *ConvPhot* software can be found in a paper by De Santis et al in this proceeding.

The *ConvPhot* algorithm allows also to produce a residual image after the fitting procedure, which can be used to detect peculiar objects which are bright in the $Ks$ band but too faint in the $z$ band to avoid the selection in the optical catalog. We have complemented the GOODS $z$-selected catalog with ~200 objects in the $Ks$ band complete down to $Ks = 23.8$ (AB) and derived the photometry of these "z-drop" galaxies in all the 14 available bands.

### *2.1. The multi wavelength catalog*

From this dataset we have obtained both a $z$–selected as well as a $K$–selected sample, with ~ 14000 galaxies with uniform photometry from the $U$ to 8.0$\mu$m bands. We have designed a Web interface to manage properly the GOODS catalog as an SQL database: the MWC Web Interface is described in a paper by De Santis et al in this proceeding.

### *2.2. Spectroscopic and Photometric redshifts*

We collect all the available spectroscopic informations in the GOODS South field (a large spectroscopic follow-up is currently underway with the FORS and VIMOS instruments at the VLT telescopes) and cross-correlate the spectroscopic redshifts with our photometric catalog. For the unobserved fraction of the objects, we apply our photometric redshift code to obtain well calibrated photometric redshifts, which are described on a forthcoming paper Grazian et al. (2005).

There are 900 known spectroscopic redshifts of high quality in the GOODS field, less than 10% of the total catalog. We have used these galaxies to check the validity of our photometric redshift recipe and found an accuracy of $\sigma_z = 0.07$. The photometric redshift code derives also the rest frame colors fitting the observed SED.

## 3. Application of the GOODS Catalog: the Distant Red Galaxies

The first application of the MWC for the GOODS field is the selection and study of the so-called DRGs, with the aim of finding early/evolved galaxies at redshift around 2-3. DRGs are important because they represent the most massive objects in the primordial Universe and it is difficult to reproduce them in current simulations (Somerville et al. 2004; Springel et al. 2005; Menci et al. 2004). Franx et al. (2003) have used the HDFS optical and NIR data to select DRGs with the color criterion $J - Ks \geq 1.3(AB)$, which turns out to be effective in isolating red galaxies at $z \geq 2$ (the

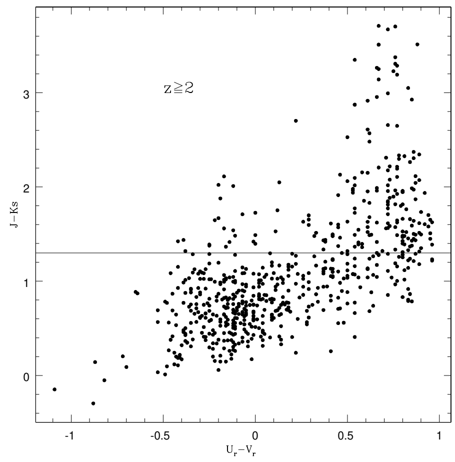


**Fig. 2.** The $J - Ks$ color compared with the $U - V$ rest frame that is useful to select the intrinsically red population in the GOODS-South region. The Franx et al. (2003) criterion selects both intrinsically blue and red objects, stressing the dichotomy of the nature of this class.

Balmer break at 4000 Å is redshifted between $J$ and $Ks$ at this redshift). They found 14 DRGs in an area of 5 sq. arcmin. In the GOODS field we have found 179 DRGs in an area of 135 sq. arcmin., an ideal sample to discern the nature of these galaxies.

The selection proposed by Franx et al. (2003), however, is not optimal, in the sense that a single color criterion will hardly isolate a well defined class of objects at relatively high redshifts. Contaminants at $z \leq 1$ are selected due to scatter produced by photometric errors in the observed $J - Ks$ color.

Indeed, the $J - Ks$ color alone can not represent the full SED of a galaxy and it is subject to the effect of redshift. If one compares the observed $J-Ks$ with the rest frame color $U-V$ of galaxies with $z \geq 2$ in the GOODS region (Fig. 2), there are intrinsically blue galaxies that are selected according to the $J - Ks$ criterion and also intrinsically red galaxies lost by this selection. In Fig. 2 one can notice clearly the bimodality in the $U - V$ rest frame even at the highest redshifts ($z \geq 2$).

The surface density (or LogN-LogS) of DRGs is represented by a power law, but its normalization is higher than that observed in the HDFS by Franx et al. (2003). The spatial distribution of DRGs, with a clustering scale comparable to the HDF size is the main responsible of the different observed densities. Cosmic variance plays a major role in deep pencil beam surveys like HDFs or UDF, but it is still present in the GOODS data, as demonstrated in the mass function results of Fontana et al. (2005).

## 4. Conclusions

The MWC catalog for the GOODS survey produced at the OAR will be publicly available at *http://lbc.mporzio.astro.it/mwcwi*, together with the softwares developed to manage large amount of complex data.

This approach to the GOODS public data allows us to develop the expertise necessary to deal with planned or future surveys, like COSMOS, two sq.deg. with the same strategy of GOODS, or those with LBC, the large field of view imager of LBT.

A detailed analysis of the properties of the DRGs (surface density, clustering, infrared colors, mass and luminosity function) will be addressed with the aim of understanding how these galaxies trace the galaxy assembly history in the Universe.

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## References

Cowie, L. L., et al. 2004, AJ, 127, 3121
De Santis, C., et al. in preparation
Fontana, A., et al. in preparation
Franx, M., et al. 2003, ApJ, 587, 79
Giavalisco, M., et al. 2004, ApJ, 600, 93
Grazian, A., et al. in preparation
Menci, N., et al. 2004, ApJ, 604, 12
Mignoli, M. et al. 2005, astro-ph/0504248
Somerville, R. S., et al. 2004, ApJ, 600, 135
Springel, V., et al. 2005, Nature, 435, 629
Vanzella, E., et al. 2005, A&A, 434, 53