Internal release of EUCLID-deep simulator

imaging and spectroscopy methods

INAF – OAR for the Astrodeep project

ASTRODEEP

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ABSTRACT

In this document we provide a description of the methods used to create the EUCLID-deep dataset of simulated images. At the conclusion of the project the dataset will include both imaging and spectroscopic simulations. Here we present the method used to create the imaging dataset that is already available and the plan to obtain the spectroscopic simulations that is currently being developed. Deliverable Number D6.1 – Delivery date December 2015.

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1. Scope of this document

The goal of WP6 is to analyse the performance of photometric procedures developed by the consortium on the imaging and spectroscopic datasets that will be obtained by the Euclid Deep Survey. This analysis will be performed on simulated data also created by the consortium. For this reason a EUCLID-deep simulator SW has been developed to emulate the entire range of anticipated EUCLID-deep products. In Period#2 the code GENCAT (now known as EGG) has been verified for accurate image simulations and has been used to create the Herschel simulated data presented in D3.2 and D3.3. After extended testing it has been shown that the same code can be used to produce images with the depth, PSF and number counts expected from the EUCLID-deep survey. This code has been used to create the simulated dataset described in D6.2. In the second section we present the method that will be used for the spectroscopic simulations that are currently in progress.

2. Simulating realistic images from EGG mock catalogs

To produce images starting from the EGG-generated catalogs, we use a Python wrapper which calls E. Bertin's public software SkyMaker, which creates realistic simulated images including sources and a (non-correlated) noise map.

The script is simple and user-friendly, to have full control of all parameters with ease. In summary, the procedure is as follows:
- the catalogs list positions and structural parameters of all the sources, in the chosen band(s)
- SkyMaker reads such list, and produces an image based on it, requiring the following additional parameters (to be given in a configuration file):
    * image size in pixels
    * gain
    * saturation level
    * exposure time
    * magnitude zero point
    * pixel size
    * seeing FWHM
    * simulated optical instrument features (mirrors diameter, etc.)
    * background magnitude per arcsecond
    * limit of allowed magnitudes

Some of these parameters are generated automatically by EGG (e.g, the dimensions of the images are chosen to match the area of the field which is being emulated, with the final images being slightly larger to fully include the extended objects near the borders, and the maximum allowed magnitude is 30.5). Others can be considered as fixed in all the possible applications of this pipeline (the simulated CCD gain is always equal to 1, and all images have HST pixels size$ps = 0.06$”; the saturation level of the CCD is 6553500 counts/s). Finally, others depend on the images set one is willing to produce (the AB magnitude zero-points, which can be set equal to 23.9 to produce counts in μJy units, or can have arbitrary values, and the exposure times).

Once all these values have been set, the only free parameter remaining to fully characterize the needed SkyMaker input is the background magnitude. However, it is easier to choose a magnitude limit at 1σ, and hence compute the background magnitude for the simulated images. To do so, we can start from the textbook formula:

$$\frac{S}{N} = \frac{\left(F_1 t_{exp}\right)}{\sqrt{\frac{F_1 t_{exp}}{g} + \frac{B_1 t_{exp} A}{g} + (R.O.N./g)^2}}$$

where:
F_1 is source flux in counts/s;
B_1 is background flux in counts/s;
A is pixel area of the source (defined by the number of FWHM within which the flux is measured); and
g is the gain, which is fixed to 1.

Assuming the R.O.N. to be zero, a source of magnitude equal tomag_{limit}has$S/N = 1$ yielding:
$1 = \frac{F_1 t_{exp}}{\sqrt{(F_1 + B_1 A) t_{exp}}}$ and therefore
$B_1 = \frac{F_1^2 t_{exp} - F_1}{A}$ where $F_1 = 10^{-0.4(mag_{limit} - ZP)}$,
and finally $mag_{background} = -2.5 log \frac{B_1}{ps^2} + ZP$.

To produce the images, SkyMaker needs their PSF, which can be generated internally or can be fed to the code as an external file; also, the transmission curve of the desired passbands are needed. In Fig. 1 and Fig. 2 we show examples of simulated datasets in GOODS-South and relevant number counts.

EGG is written using phy++, a free and open source C++ library for fast and robust numerical astrophysics. The actual code can be downloaded from an online repository: https://github.com/cschreib/egg

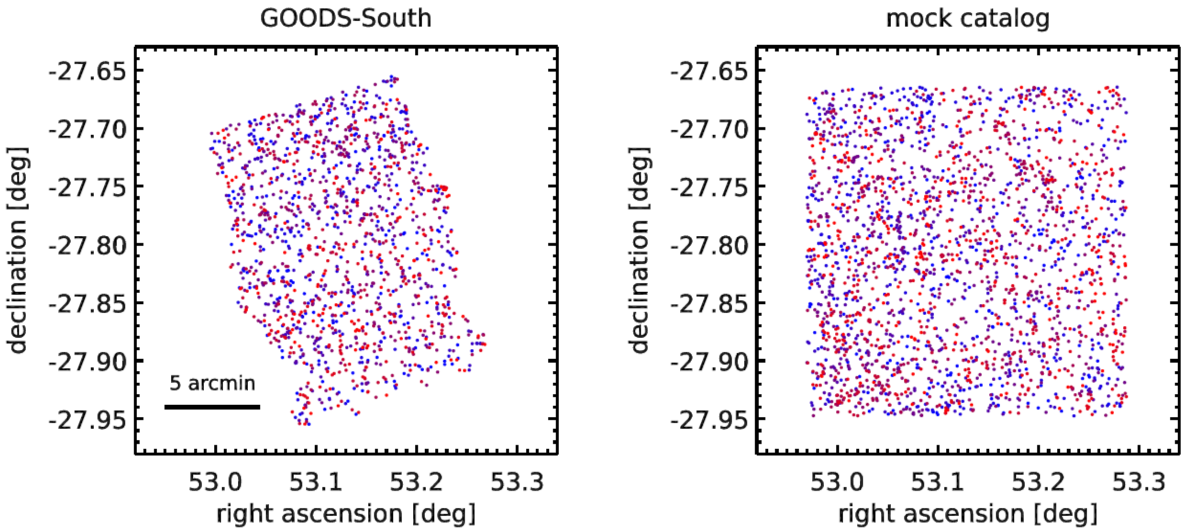

Fig. 1: Left: Sky positions of the galaxies in the GOODS–South field with $M_* > 3 \times 10^{10} M_\odot$. Colors indicate redshift. Right: Same as left, but for the mock catalog produced with EGG.

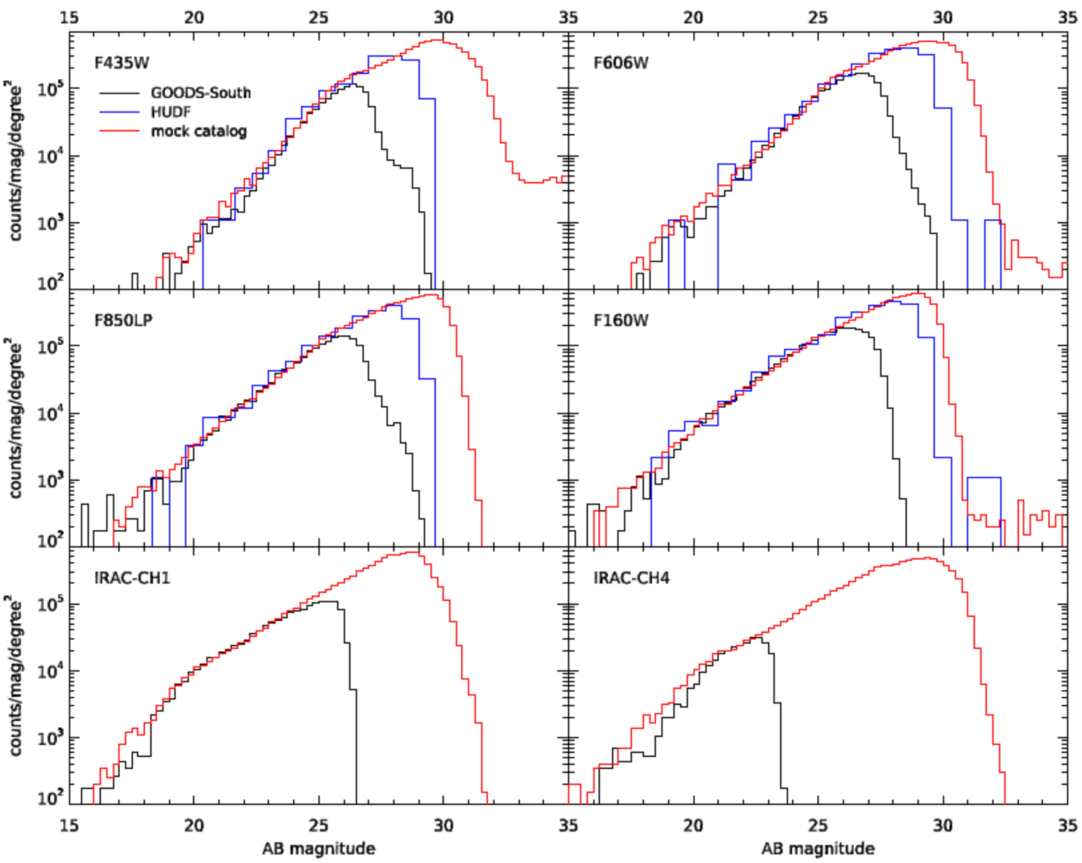

Fig. 2: Observed magnitude distribution from the HST B -band up to Spitzer IRAC 8 _ m. The simulated fluxes (red histogram) come from a mock field of 10'x10' that is complete down to H < 29. These are compared to the observed fluxes in the Hubble Ultra Deep Field (HUDF, blue) and the rest of the GOODS–South field (shallower, in black). Observations in the HUDF are only shownfor the Hubble imaging, since the Spitzer images are not deeper in this region.

A link and more details about the code can be found also on the Astrodeep webpage: http://www.astrodeep.eu/egg-simulations-software/

Simulations for the *Euclid* Deep Spectroscopic Survey

December 21, 2015

1 Motivation

The *Euclid* deep imaging survey is expected to observe the sky over 20–40 square degrees in four filters (O, Y, J, H) to corresponding 5-sigma imaging depths of 27.5, 26, 26, 26 (AB mag). This combination of filters and depths will make the survey ideal for photometrically identifying galaxies at $z > 6$ via the Lyman-break technique, providing an unprecedentedly large sample of UV-bright galaxies during the epoch of re-ionization, over spatial scales which should make it possible to observe key signatures of the re-ionization process. In order to achieve this however, the photometric observations will require deep follow-up spectroscopy. This spectroscopic data is required in order to measure the evolution of the Ly α emitter fraction as a function of redshift, along with the spatial clustering of Ly α emitting galaxies with respect to the underlying Lyman-break population. Using these observations it will be possible constrain two key aspects of cosmic re-ionization models: (i) the redshift evolution of global neutral Hydrogen fraction; (ii) the extent and distribution of ionized gas 'bubbles' surrounding the largest halos as re-ionization proceeds (e.g. McQuinn et al., 2007, MNRAS, 381, 75).

The primary motivation of our work package is to provide to the community a simulated spectroscopic dataset of a 20 square degree field, including accurate population statistics, clustering and emission properties of $z > 6$ galaxies, in order to assess the feasibility and requirements of these observations. The simulations must also accurately represent the $z < 6$ population in order to assess the impact of contamination from foreground galaxies, particularly with regard to strong line emitters at $1 < z < 3$ where the prominent H α, H β, [O III] and [O II]λ3727 emission lines fall within the observed wavelength range. With this in mind we do not intend to focus on creating a bespoke *Euclid* grism simulator, since an official *Euclid* grism simulator (`TIPS`) (Zoubian et al., 2014, ASPC, 485, 509) is being developed within the *Euclid* consortium in conjunction with the official grism data reduction pipeline which will be used on the actual *Euclid* data once it is being taken. Instead, our focus will be on generating a simulated grism image with galaxy catalogues and spectra as realistic as possible for assessing the high-redshift science goals of the *Euclid* Deep Survey. Such a dataset would be a unique and valuable contribution to the high-redshift science community in preparation for the *Euclid* mission, and we will liase with Dida Markovitch at Portsmouth (who is also working on NISP simulations using IMODEL (Franzetti et al.) and PROFESS (de la Torre et al.)) to ensure effective exchange of ideas and information to maximise the realism and usefulness of the final simulations.

We intend to release to the community both the input 20 square degree catalogue along with the simulated grism images. Below we give a brief description of the spectroscopic instrument to be used in the *Euclid* mission, and an outline of our plan to produce a simulated dataset within the required timeline.

2 Instrument Description

The Near Infrared Spectrometer and Photometer (NISP) instrument on board *Euclid* will provide the near infrared photometry and spectroscopy required for these observations. The NISP focal plane is equipped with 16 2000×2000 detectors (with 0.3 arcsec pixels) covering in total a field of view of 0.53 square degrees. Each spectroscopic unit will be equipped with four different low resolution ($R = 350$) near infrared grisms, three 'red' ($1.25 - 1.85\,\mu$m) and one 'blue' ($0.92 - 1.25\,\mu$m). Therefore, the 20 square degree *Euclid* Deep Survey will be comprised of ~ 40 separate pointings of the telescope, yielding 40×16×4 (= 2560) individual grism frames to be simulated as a minimum. The wavelength coverage means the Ly α line will fall within spectroscopic channels in the redshift range $6.6 < z < 14.2$[1]. The three red grisms will be orientated at three different position angles in order to aid with the de-confusion of overlapping spectra in slitless spectroscopy. The putative 5σ line limit of the deep survey is 5×10^{-17} erg s^{-1} cm^{-2}, which corresponds to a Ly α rest-frame equivalent width detection limit of ~ 80Å at $J \simeq 26$.

3 Outline of Work Plan

Below we give a detailed description of the intended work-flow of this project. A general outline of this work-flow along with expected completion dates is given in Fig. 1.

1. As an initial experiment we will run `TIPS` for one *Euclid* pointing (0.53 square degrees) using Corentin Schreiber's code `EGG` to generate a mock galaxy catalogue. For this initial experiment we will not focus on the accuracy of the catalogue but only on successfully running `TIPS` to generate the grism images and extract the 2D galaxy spectra. This is simply a preliminary test to get to properly understand and refine the various software components we will be utilizing.

2. We will assess the effect of using multiple dispersion orientations to de-confuse the grism images and correct for the overlapping of spectra. This experiment does not need to necessarily be done using `TIPS` since it is a general principle of any grism spectroscopy and not a problem unique to the *Euclid* mission. As an alternative we could use the `aXeSIM` simulation package for the WFC3 grisms on the *HST*. This would have the advantage of much reduced computation time since *HST* has a much smaller field-of-view, however is must be borne in mind that the *Euclid* PSF is $\sim 2\times$ worse than *HST* therefore the probability of spectral overlap is correspondingly increased. We do not assume that will be able to dictate the number of different orientations utilized in practice for the final *Euclid* mission, however these tests will provide useful information concerning the optimum number of orientations and how complete a spectroscopic sample can be anticipated given the number of orientations used. We also expect to develop algorithms for optimally stacking 2D spectra across multiple orientations. These tests can be run in parallel to the main aim of the work package.

3. Once we have become accustomed to running the `TIPS` software, we will focus on including realistic emission line SED's in the simulations. In particular we will focus on generating SED's with realistic emission-line luminosities for galaxies at $z > 1$. To do this we can utilize work being undertaken within a separate project

[1] $6.6 < z < 9.2$ for the 'blue' grism and $9.2 < z < 14.2$ for the 'red' grism. The blue grism will be the primary filter for the $z > 6$ science case.

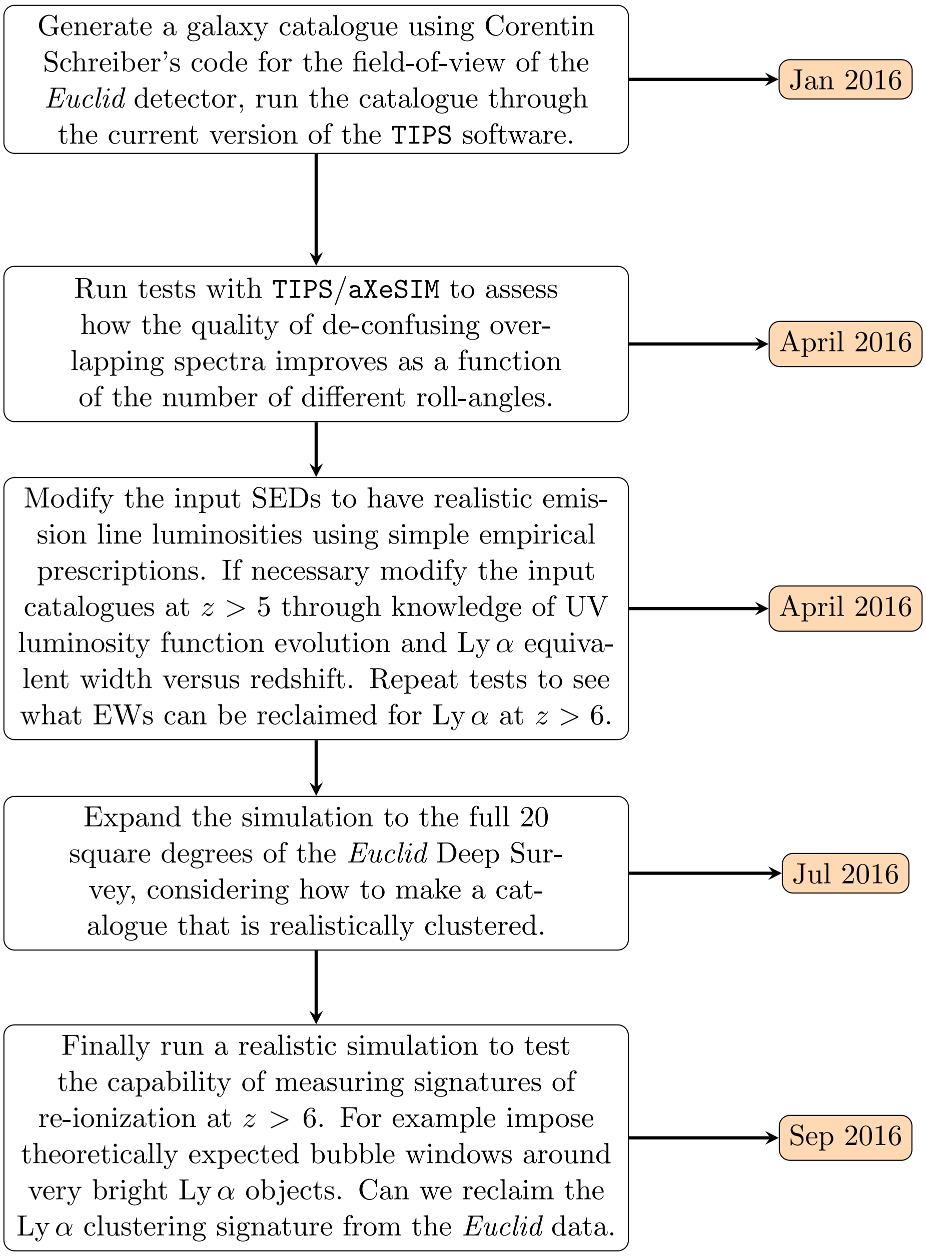

Figure 1: General work-flow for producing the *Euclid* spectroscopic simulations along with estimated completion dates.

generating high-redshift galaxy SED's from the First Billion Years (FiBY) simulation (Paardekooper et al., 2013, MNRAS, 429, L94) using a combination of stellar synthesis and photoionization modeling. Alternatively we may use simple empirical prescriptions based on, for example, the expected star-formation rate, metallicity and stellar mass of the galaxies. We will also focus on making sure the population number counts in the `EGG` catalogues are accurate for the $z > 6$ population. With these SED's we will first quantify the range of Ly α equivalent widths we expect to be able to detect at the depth of the *Euclid* Deep Survey. We will also assess the impact of $1 < z < 3$ emission line contamination on the $z > 6$ spectra.

4. With this realistic set of galaxy SEDs we will focus on producing the final galaxy catalogue and the full simulated image of the 20 square degree field of the *Euclid* Deep Survey. This will form the final data product that will be released to the community. Given one of the main science drivers of these simulation is to measure the clustering signal from re-ionization, we are anticipating the possibility of having to modify the input catalogues generated by `EGG` to ensure that the $z > 6$ galaxies are realistically clustered. This can be achieved by various means, one option being to combine `EGG` with light cones produced from galaxy-formation models embedded in dark-matter simulations (e.g. Croton et al., 2006, MNRAS, 365, 11).

5. Finally we will modify the full 20 square degree simulation to attempt to test the possibility of recovering the clustering signal of re-ionization with the *Euclid* Deep Survey. For example by imposing bubbles around Ly α emitters depending on the assumed star-formation rate, age, escape fraction and redshift (e.g. McQuinn et al. 2007) we can generate a variety of toy models. We will be able to test the clustering signal recovery as a function of the assumed model, to test the feasibility of observing this signature of re-ionization with the *Euclid* mission.