Crowded-field image simulator for WSO-UV/ISSIS: first functional version developed by the Glendama team

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Received: 17 January 2014 / Accepted: 12 September 2014 / Published online: 24 September 2014
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Abstract We are developing a web-based interactive software to simulate crowded-field imaging with ISSIS on board the future WSO-UV. This new tool is aimed to prepare WSO-UV/ISSIS proposals to observe multicomponent targets and dense fields. For a given combination of UV channel, filters and exposure time, the user creates a set of point-like and extended sources (source model). This source model produces a final image, which takes into account a pixelated field of view, a realistic conversion between physical flux and counts per second, the convolution with the expected point spread function, a sky background and noise fluctuations. The current version of the simulator is available at the Glendama website, and it allows users to specify all relevant parameters of each point-like or extended source, drag-and-drop sources by using a mouse or a fingertip/stylus on a touchscreen, change the frame size or the brightness scale, etc.

Keywords Ultraviolet astronomy · Space telescopes · Astronomical image simulation · Gravitational lensing

1 Introduction

The Imaging and Slitless Spectroscopy Instrument for Surveys (ISSIS; Gómez de Castro et al. 2012, 2014) will be one of the two main science units (the WUVS spectrographs are the other) on board the World Space Observatory-Ultraviolet (WSO-UV) mission (Sachkov et al. 2014a,b; Shustov et al. 2014), which is intended to be launched in 2017. This UV space observatory will incorporate an 1.7 m telescope, and it is expected to operate for about 10 years.

The imaging mode of ISSIS should allow astronomers to resolve the fine structure of faint UV sources, as well as multiple faint sources in dense fields. This is because the small pixel scale, compact point spread function (PSF) and high sensitivity of the instrument (Gómez de Castro et al. 2014). Each ISSIS image (2048 × 2048 pixels) or sub-image will be the convolution of a brightness distribution (generated by sources inside the corresponding field of view) with the PSF. The sky background and noise fluctuations will also play a role.

To accurately model ISSIS sub-images of crowded fields, we are making a free, web-based interactive software (see Fig. 1). In Sects. 2 and 3 we give detailed instructions for potential users of our crowded-field image simulator (CIS), while in Sect. 4 we present some examples of using the CIS. Section 5 includes some final remarks on the new tool and its applicability to study gravitational lens systems in the UV.

2 User guide

The CIS is available at the Glendama website. Click on the URL: http://grupos.unican.es/glendama/CIS.html to start this simulator. Your browser will open a main window that contains empty frames of 512 × 512 (or 256 × 256) pixels covering 18.4″ × 18.4″ (or 9.2″ × 9.2″) on the sky (see Fig. 1). In the current version, the initial frame dimensions depend on the size of your screen, and the pixel scale is 0.036″. Later you can reduce the field of view and go into
2. Random distribution

You can put the pointer on any point-like or extended source to see its parameters: $x, y, F$ (point-like) or $x, y, F, R_{1/2}, \epsilon, PA$ (extended). You can add as many sources as necessary, change the position of any object (click on it, drag and drop) and remove it (double click).

The source model leads to a final image in the right-hand frame. First, physical fluxes (in erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$) are converted to counts per second (cps) using a realistic cps-to-flux ratio for the corresponding channel, i.e., $3.36 \times 10^{15}$ (FUV) or $1.14 \times 10^{17}$ (NUV). These ratios are properly reduced when using a neutral filter (see above for transmittance factors). Second, the source model is convolved with the expected central PSF for the FUV/NUV channel. Third, a sky background is added to the image. This is due to the Earthshine (ES), the Zodiacal light (ZL) and the Geocoronal emission (GC), and we take the ES, ZL and GC average fluxes in the Hubble Space Telescope (HST).\(^1\)

The ES flux for the WSO-UV telescope should have smaller values than those for the HST, because the higher Earth orbit of the WSO-UV (less affected by the reflected sunlight). However, although the ES contribution is overestimated, the total background (based on the ES, ZL and GC average fluxes in the HST) is dominated by the GC signal: $ES < ZL < GC$. This sky background depends on the selected channel and filters, and its open-open values are $\beta = 4.9 \times 10^{-3}$ cps/pix ($ES + ZL = 7.2 \times 10^{-12}$ cps/pix) in the FUV and $\beta = 3.5 \times 10^{-4}$ cps/pix ($ES + ZL = 2.1 \times 10^{-5}$ cps/pix) in the NUV. The current version of the simulator does not account for any instrumental background (e.g., dark current).

In a final step, the simulator takes into account the exposure time ($T$ in sec) to produce a number of counts in each pixel, and then generate Poisson fluctuations. The final image initially displays counts in pixels ($C$), but the user is allowed to modify the brightness scale, i.e., $\log(C)$ or $\sqrt{C}$ instead of $C$, or zoom the image. We note that the logarithmic scale is related to magnitudes. In addition, the signal-to-noise ratio (per pixel) is given by $SNR = (C - B) / \sqrt{C}$, where $B = \beta \times T$. Hence, the square-root scale is useful to quantify the SNR when $C \gg B$.

3 Saving and handling simulations

You can save the source model and the final image to your computer by clicking on the “PNG” labels above both

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\(^1\)See documents on the HST UV background at http://www.stsci.edu/hst.
frames. After each click, your browser will open an additional window displaying the corresponding PNG file. This file can be stored in a suitable folder using the browser command “File/Save as...”.

Regarding the final image, it is also possible to display on your screen and save a red-green-blue-alpha (RGBA) data file. This RGBA data file contains information to reconstruct the simulated brightness map. The $C$ values are described from the 3 colour (RGB) indexes. The opacity ($A$) index does not play a role, and

$$C = R + 256 \times G + 256 \times 256 \times B.$$ (1)

Here below we describe a simple way to reconstruct the final image in standard FITS format. This recipe only relies on commonly-used astronomical software (DS9 and IRAF).

**Recipe for cooking data** Click on the “RGBA data” label to show this file on your screen. You can then save it in PNG format, e.g., image.png. Open your DS9 viewer and select “Frame/New Frame RGB” and “File/Import/PNG...”. Then you should import the file of interest (image.png). In the RGB panel of DS9, select “Current/Red” and save the corresponding FITS file, i.e., “File/Save/R.fits”. Then select “Current/Green” and save G.fits, and also select “Current/Blue” and save a third file called B.fits. Now you need to combine the three FITS files to obtain the simulated brightness map as a FITS image. This task can be done in an IRAF environment. Taking Eq. (1) into account, the IRAF commands are:

```
cl>imar G * 256 G
cl>imar B * 65536 B
cl>imar R + G RG
cl>imar RG + B image
```

The final product (image.fits) is ready to be analysed in detail. You may use your favourite analysis software to explore the scientific return of the simulated observations, and thus, check the ISSIS performance and prepare observation proposals.

### 4 Simulation examples

This section describes the steps to simulate a few crowded fields. In each simulation, we start with empty frames of 512 x 512 pixels (see Sect. 2).

1. **Two galaxies that are blended together**
   - go to the “Source parameters/specific” table and put the cursor in the “ellipticity” box. Enter an $\epsilon$ value of 0.7 (its default value is 0.5);

![Fig. 2 ISSIS sub-image of 128 x 128 pixels. Left: Two galaxies with exponential profiles. Both have the same central position ($x = y = 256$), flux ($10^{-14}$ erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$), $R_{1/2}$ value (20 pix, or equivalently, 0.72") and ellipticity (0.7). However, their position angles differ by 90 deg. Right: Final image using the default configuration: NUV channel, open-open, $T = 100$ sec. We also use the logarithmic brightness scale](image.png)

2. **500 random stars**
   - select “Source parameters/Point” and the “random” option;
   - choose the value 100 in the drop-down menu for the “number of sources”;
   - click 5 times on the “add source(s)” button.

In order to explore the star shape in the final image (see the right panel in Fig. 3), you can use the zoom control.

3. **100 random galaxies**
   - select the “Source parameters/random” option;
   - choose the value 100 in the drop-down menu for the “number of sources”;
   - click on the “add source(s)” button.

You can find details on the random sample of galaxies in the “List of sources” (see also Fig. 4).

### 5 Concluding remarks

The World Space Observatory-Ultraviolet is a cosmic mission that will provide data about a large variety of targets.
Many of these targets would have complex structures and/or would be located in dense fields, and thus, the crowded-field image simulator for ISSIS is expected to play a relevant role in the development of observation strategies. This new publicly available tool is designed to be powerful, yet user-friendly and intuitive. Users do not need to install the simulator, and only a web-browser is required to use the tool. If the software at the Glendama website is downloaded to a local computer, then the simulations can be also performed in an off-line mode (without Internet connection).

Thanks to the implementations in JavaScript language, the new simulator combines simplicity and functionality. In recent years this language is evolving significantly faster than in its origins, and is being converted into a powerful calculation tool. For example, we use a 2-dimensional fast Fourier transform (2D FFT) on large grids, which was hard to imagine several years ago. At present, other astronomy teams are actively developing JavaScript software or transferring desktop applications to web with JavaScript (e.g., the JS9 web implementation of the well-known DS9 FITS viewer). These tasks will be accelerated during next years and our simulator is one contribution to this ongoing process.

The current version of the simulator does not incorporate all filters that will be available. Hence, we plan to take into account the different filter responses, and incorporate this information into a future version of the simulation tool. We also want to improve the adopted background and make easier (if possible) the obtention of final images in FITS format (to subsequent analyses). This final version should be available to the community before the first calls for proposals and the launch of the WSO-UV mission in 2017.

We belong to the WSO-UV/ISSIS Science Working Group, and are involved in the preparation of a large observation program to analyse optically-bright lensed quasars in the UV (Goicoechea et al. 2011). In more detail, using the CASTLES3 and SQLS4 databases, we selected 41 systems in the redshift interval \(1 < z < 3\). The key idea is to carry out two subprograms with this sample or part of it. The first subprogram aims to build an UV database (disentangle nuclear and circumnuclear EUV emissions, etc.), while the second one focuses on an UV monitoring (variability of the nuclear continua). Although preliminary estimations support the feasibility of both programs, we will use the final simulator to check all details and apply for observing time on the future space observatory.

Acknowledgements This research has been supported by the Spanish Department of Science and Innovation grant AYA2010-21741-C03-03 (Gravitational LENses and DArk MAtter—GLENDA MA project), and the University of Cantabria.

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2See updates at http://grupos.unican.es/glendama/.
3http://www.cfa.harvard.edu/castles/.
4http://www-utap.phys.s.u-tokyo.ac.jp/~sdss/sqls/.