

AETC: Advanced Exposure Time Calculator

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ABSTRACT

We describe a tool (AETC: *Advanced Exposure Time Calculator*) to simulate images of astrophysical objects obtained with any combination of telescope, instrument and given pass band using a suitable set of parameters that define the configuration of the equipment used for the observations. The tool provides count rates and its distribution over the focal plane, through the proper definition of the PSF, of virtually any telescope equipped with an imager provided that its configuration is assessed. Effects of non-uniform PSF over the Field of View can also be modeled. Moreover, detailed simulation of the observed fields can be simulated including stars, galaxies and more complex objects providing template of the targets. The tool is available at: <http://aetc.oapd.inaf.it/>

Keywords: Telescopes, Astronomical Instruments, Astronomical Observations, Exposure Time Calculator, Simulation, Imaging

1. INTRODUCTION

In the modern era of telescope observations it is a common use to estimate the required exposure time to reach the desired signal to noise ratio of the proposed observation. This is a standard practice for all observations secured by space based instruments and has become common also for ground based telescopes, although for the latter the correct estimation of the exposure time depends on the environmental conditions during the observations (e.g. sky background, seeing, ...). The use of ETCs, that is becoming a standard practice in many observatories, allows the observer to evaluate the exposure time requested to obtain the desired data and to ensure that telescope observing time is optimized for the proposed scientific objectives. In spite of possible differences between the expected (computed by ETC) signal-to-noise ratio and that obtained during the real observations (mainly due to different observing conditions), the use of ETCs has greatly contributed to optimize the results from the observing programs.

Another, but less common, use of an ETC is in the context of design and concept study of new telescopes and instrumentation. In this case the use of an image simulator offers the possibility to evaluate the science capability of new instrumentation and to perform end to end simulations of specific science cases.

2. ADVANCED ETC

The standard result from all ETC is to know the required exposure time to reach a specific S/N for a given observation under specified conditions. Most of the great modern observatories offer a tool to estimate the requested exposure time for the desired observations. Examples of such tools (designed for specified instruments) are given in :

ESO : <http://www.eso.org/observing/etc/> ;

CFHT : <http://www.cfht.hawaii.edu/Instruments/Imaging/Megacam/dietmegacam.html> ;

WHT : <http://catserver.ing.iac.es/signal/>

The main (and often only) task of these tools is either to provide S/N for a given observation or viceversa to state the required exposure time to reach a given S/N. The Advanced ETC described here has many advantages wrt these tools:

1. a great possibility to change the parameters of the adopted instrumentation and/or the conditions of the observation.
2. the possibility to include any user defined specified element (pass band of the filter, detector sensitivity, input signal from the source, etc)
3. but the most important difference of AETC tool with respect to standard ETC is the capability to produce simulated images of a large variety of targets assuming a given instrument configuration; these simulated images may contain both stars and galaxies (through a model) that are convoluted with the specified Point Spread Function (PSF).

2.1 The tool

AETC is available at : <http://aetc.oapd.inaf.it/> . A number of configured instruments are available for testing. These include a standard 2m telescope with an imaging camera, ESO-VLT + FORS , TNG + Dolores, HST + WFPC2 and E-ELT + MICADO. An empty template is also available to allow the user to define his/her own instrument. Once the new configuration is assessed it can be saved in a configuration file that can then be reloaded for further uses (see Figure 1 and 2)

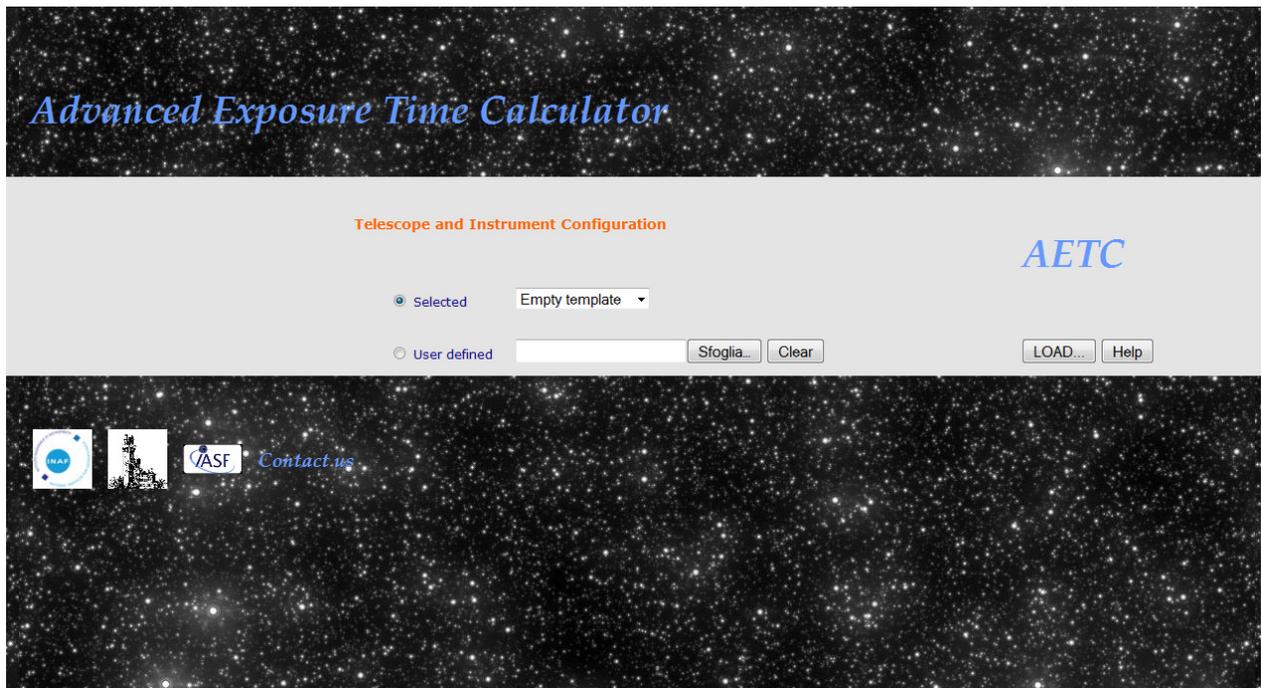


Figure 1. The AETC home page (<http://aetc.oapd.inaf.it/>). A list of pre configured telescope + instrument combination are available as well as a user defined configuration.

2.2 Instrument parameters and background

In this section the main parameters that define the telescope and the instrument can be defined through a number of efficiency tables for the optics, the instrument and the detector. All relevant fields may be filled with three different type of input: a constant value, a configured specific table (e.g. the efficiency of a detector), and a user defined efficiency table for a given element of the configuration (telescope mirror, instrument, etc).

Object: AETC Save input configuration as: SEND... **AETC**

Telescope and Instrument Specifications

Primary mirror Ø (cm): 800 Number of reflection: 1 Fraction of Obstruction: 0.2 Plate Scale (arcsec/pixel): 0.25

Mirror Reflectivity: Constant Table: UT1_optics By User: Clear Sfoggia...

Instrument Efficiency: Constant Table: FORS_optics By User: Clear Sfoggia...

Detector Efficiency: Constant Table: FORS_ccd By User: Clear Sfoggia...

Sky Brightness

Constant Mag/arcsec²: Band: select Mag System: select Table: Paranal By User: Clear Sfoggia...

Figure 2. The AETC instrument configuration panel.

In addition the sky background can be set using a constant value of the surface brightness, standard values for selected observatory sites or specific user defined values.

2.3 The observation parameters

The observation can be specified through a number of parameters that define the spectral shape (black body, power law or template) and the flux (or the magnitude in various systems) of the object and the specific exposure time.

A critical element for the evaluation of count rate, S/N and the simulated image is the definition of the Point Spread Function. It can be modeled by a Gaussian or Moffat function, from the 1D radial average brightness profile and also from a complex 2D fits image. For modeling variable PSF there are two options available: 1) providing a 3-D data cube containing 2D PSF images (fits file) computed (or measured) at different positions in the field of view (the position of the PSF in the data cube are listed in a separate text file). The PSF is then computed at each position of interest (x0,y0) by a weighted average of the closest PSF included in the data cube, weighting each PSF template with the inverse of the distance from x0,y0. 2) providing a stretching map that describes the changes of the PSF model (fits image) as for the ellipticity, the FWHM and position angle along the FoV.

Observation Parameters

Observation Band: λ range Å Table V

By User

Total Exposure Time (sec)

Number of Exposure

Readout Noise (e⁻)

Aperture Ø (arcsec)

fixed Encircled Energy

Encircled Energy: seeing limited seeing function FWHM (arcsec)

psf PSF function

PSF Table

PSF user file

Source Specifications

Single Object

SED: Black Body $\%k$ Template Table

Power Low Spectral index By User Redshift

Flux: computed Magnitude Band Mag System

direct input Flux(λ_0) λ_0

Figure 2. TOP: The AETC panels that describe the observation parameters including the definition of the Point Spread Function of the instrument. BOTTOM : The spectral characteristics of the input source.

2.4 Count rates and simulated images

The first aim of the tool is to provide count rate of the source, of the background and to evaluate the signal to noise ratio in a given area of the object imaged. This is accomplished by the tool taking into account all the parameters that define the instrument throughput and the background conditions. The S/N depends on the properties of the target, on the parameters of the observation and on the PSF that are specified in the *Observation Parameters* and *Source Specification* sections. Example of such output is show in graphical form in Figure 3.

Input configuration

Object: AETC
Primary mirror diameter: 800 cm
Plate scale: 0.25 arcsec/pixel
Number of reflections: 1
Fraction of obstruction: 0.2
Observation band: V 4800.0 - 7200.0 Å
Photometric system: UBVRI_Johnson
Mirror reflectivity: UT1_optics
Instrument efficiency: FORS_optics
Detector efficiency: FORS_ccd
Sky Brightness: Paranal, mag: 21.61 in AB mag system
Exposure time: 1000sec
Number of exposure: 1
Readout noise: 3e-
Aperture Ø: 1.0 arcsec
Encircled Energy: 0.84 seeing limited, Moffat function, FWHM:0.5
Single Object - SED: Stars g0v (1150.0 - 10620.0) Å
Input: mag: 20, band: V, mag system: AB
Star file: No Star file
Galaxy file: No Galaxy file
Object file: No Object file

Aperture Output Signals:

Collecting area: 482548 cm²
S/N area: 12.6 px
Source: 1.445227e+06 ph/aper/expT
Background : 3.124912e+05 ph/aper/expT (24.87 ph/sec/px)
StoN 1090.05
Zero Point 28.09

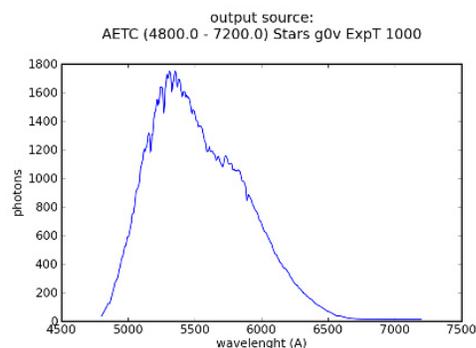
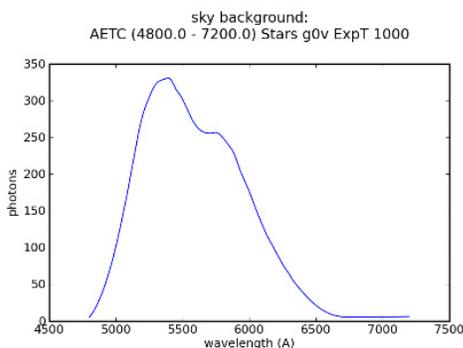
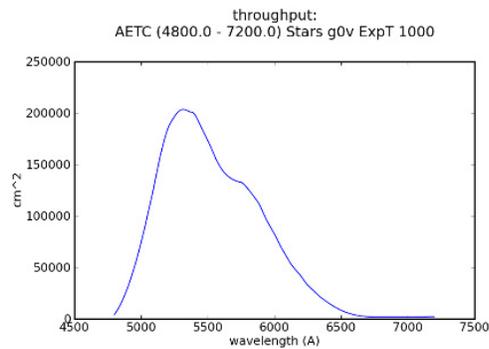
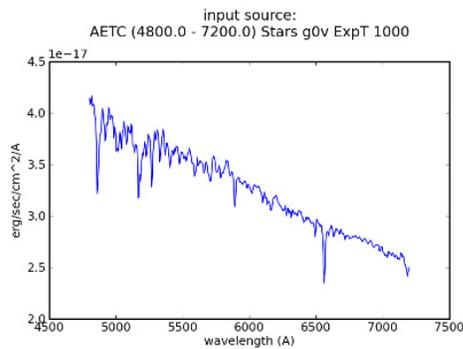


Figure 3. The input source (top-left panel) is imaged through the selected telescope and instrument configuration (in this case V filter) with the throughput (top right panel) and the defined background (bottom left panel) yielding the output count rate (bottom right panel). The input and output parameters are summarized in the Table above.

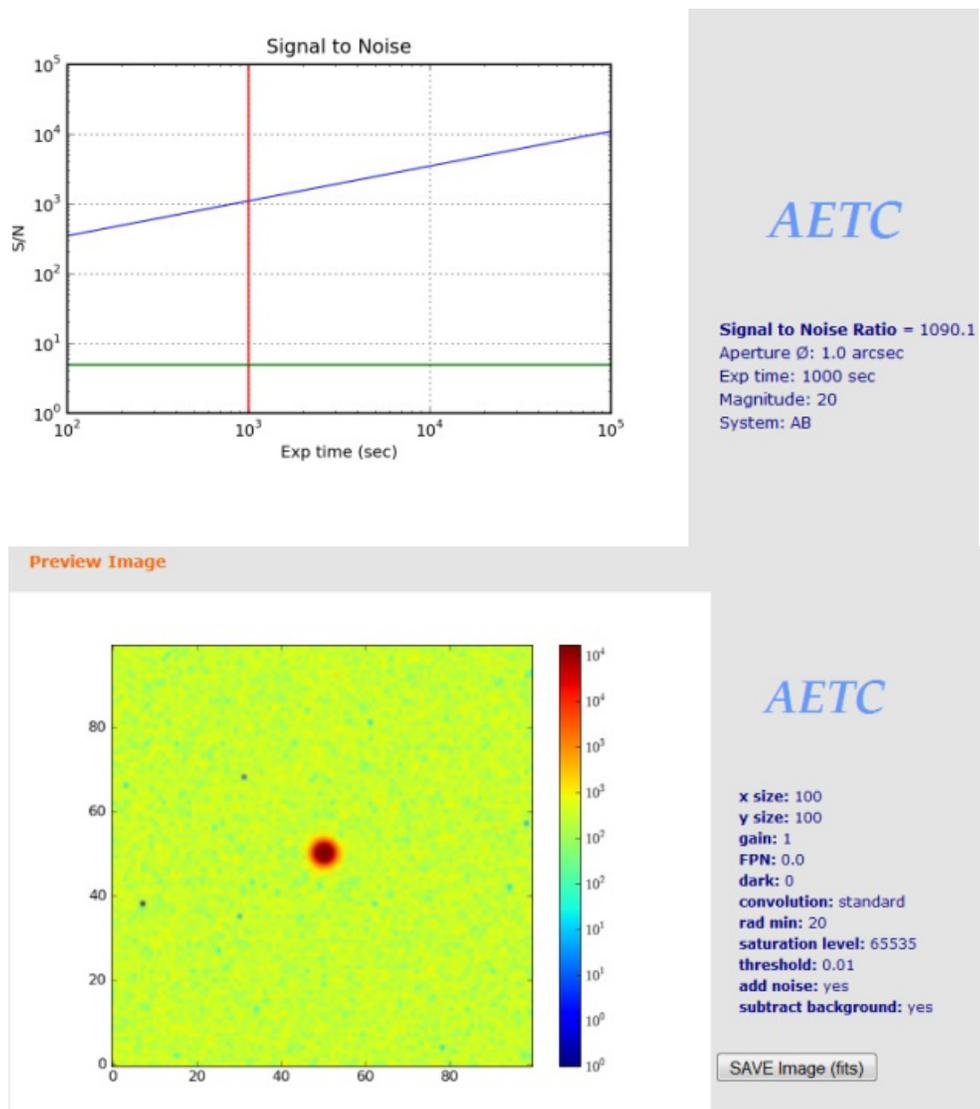


Figure 4. Top: The expected S/N of a simulation as a function of total exposure time. Bottom: preview of the image of the simulated object

2.5 Image simulator

The module which generates the simulated images was developed in IDL. The tool takes in input the adopted configuration and a set of files containing the positions and the properties of the objects stars, galaxies and templates for complex targets. Stars and galaxies are generated by using the PSF model and by convolving galaxy models with the PSF.

Complex Objects are instead simulated from a user-provided template: this allows introducing sources with complex features, providing an image of suitable resolution. One of the key features is how the simulator can manage the PSF: it can manage several kinds of PSF, from very simple models, constant in the field of view, to complex models taking in account the spatial dependency in various ways. In the case of a constant PSF, the model can be provided as a 1-D profile or a 2-D image.

Galaxies are modeled by convolving a Sersic law $I(r)$ with the PSF and giving the coordinates of the center, the total magnitude, the index of the Sersic law, the half light radius, the ellipticity and the position angle of each galaxy

$$I(r) = I_0 \frac{e^{2n-0.331} n(2n-0.331)^{-2n} \Gamma(2n)}{2\pi \cdot r_e^2 \cdot (1-\varepsilon)} e^{-(2n-0.331) \left(\frac{r}{r_e}\right)^{1-\varepsilon}}$$

where r is given by the relationship

$$r(x, y) = \frac{1}{r_e} \sqrt{\left((x-x_0)\cos\theta + (y-y_0)\sin\theta \right)^2 + \left(\frac{-(x-x_0)\sin\theta + (y-y_0)\cos\theta}{1-\varepsilon} \right)^2}$$

To save computation time, all the simulated sources can be computed only up to a radius where their contribution goes below a given fraction of the noise.

3. EXAMPLES OF SIMULATION

The above tool was used to evaluate the imaging capabilities of the “Multi-AO Imaging Camera for Deep Observations”, (MICADO²) designed to work with adaptive optics (AO) on the E-ELT (<http://www.eso.org/sci/facilities/eelt/>). MICADO has been designed and optimized to be mounted to the LGS-MCAO system MAORY¹, and will provide diffraction limited imaging from 0.8 μm to 2.4 μm over a wide (1 arcmin) field of view.

3.1 Stellar field of a distant galaxies.

One of the key science cases for the construction of Extremely Large Telescopes concerns the possibility of studying the resolved stellar population in distant galaxies. This kind of studies requires to perform accurate photometry in very crowded fields in order to construct the color magnitude diagrams that can be used to uncover the star formation history.

In Figure 5 we show the simulated 1 arcsec field of a central region of a disk galaxy in the Centaurus group (distance 4.5 Mpc) using the parameters of the (phase A study) for MICADO² coupled with adaptive optics module MAORY¹ for the E-ELT. The simulated image and the subsequent analysis³ show that with this instrumentation it will be possible to investigate (directly from the stars) the distribution of ages of the various stellar population in distant galaxies.



Figure 5. The 1 arcsec FoV of a disk galaxy in the Centaurus group from the simulated stellar population as would be imaged by MICADO @ E-ELT (5 hours integration in J band).

3.2 Deep field of faint galaxies

Another example of simulation concerns the case of a deep field of galaxies. In Figure 6 we show the image of a simulated deep field of galaxies as can be observed by an 8m class telescope from the ground under good seeing conditions. The galaxies are modeled using the Sersic law described above and convolved with the PSF (seeing function). The galaxies have a homogeneous distribution of Sersic index, scale length, magnitude and orientation. Faint stars are also included in the field.

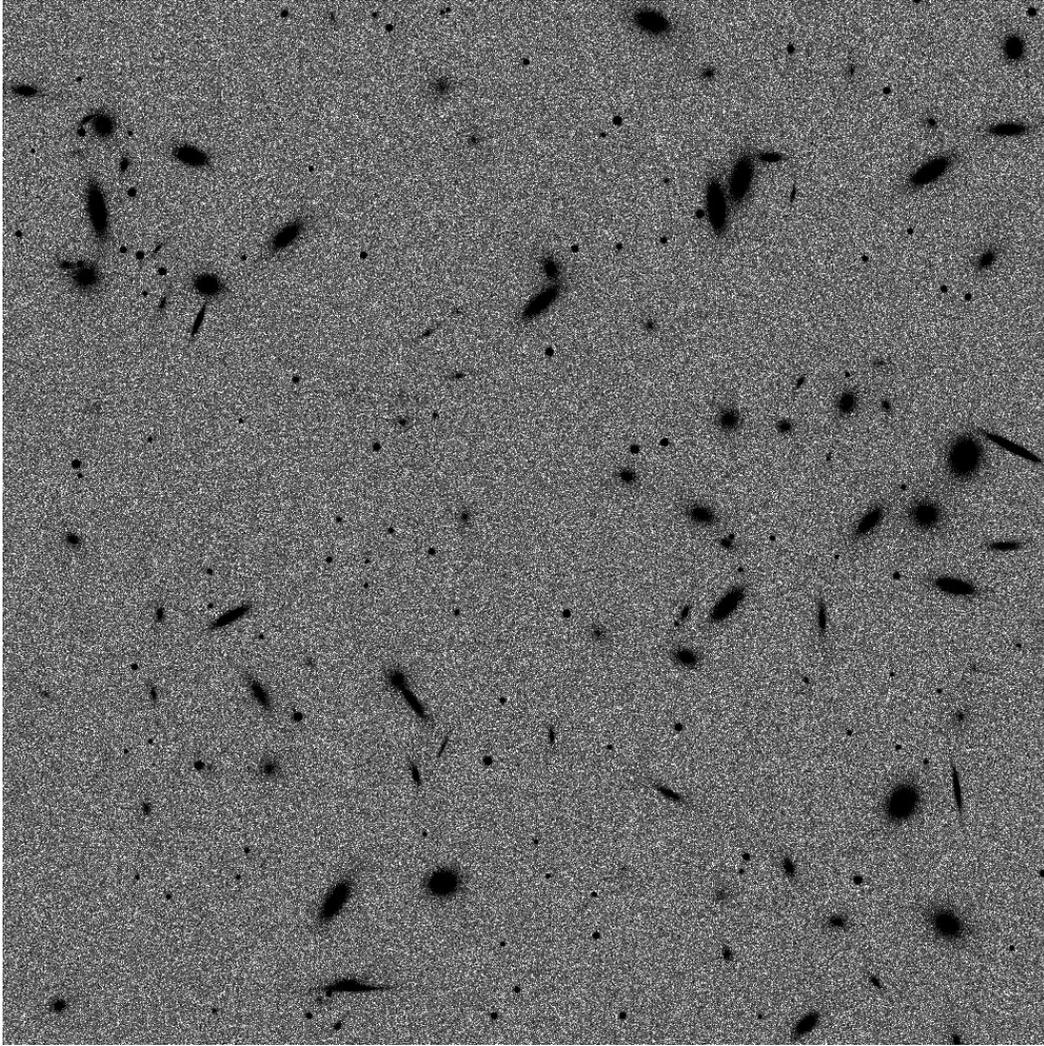


Figure 6. Simulated deep field of galaxies ($R=20$ to 25) as observed by a 8m telescope under 0.7 arcsec seeing in the R filter in 1000 seconds.

3.3 Morphology of $z = 1-2$ galaxies

The physical processes driving galaxy formation and evolution are still an enigma. Given the most recent results from high resolution studies (imaging and integral field spectroscopy, from the ground or from space) it is now becoming clear that galaxies at redshift $z \sim 1 - 4$, when they were undergoing their most rapid phase of stellar mass assembly, are smaller and of complex morphology.

In this respect high resolution imaging of $z > 1$ galaxies will thus be crucial for a proper understanding. Their typical sizes are $\sim 0.2 - 0.3$ arcsec at $z \sim 2 - 4$, decreasing at higher redshift roughly like $1/(1+z)$ at fixed rest-frame luminosity and decreasing with lower luminosity (roughly like $L^{0.5}$). Spatial resolution (coupled with sensitivity) is the main limitation for this kind of studies. To be able to detect individual structures of size ~ 100 pc at $z = 1-4$ a resolution of ~ 12 mas is required. This is well matched by MICADOE-ELT. Examples of simulated images of high redshift galaxies are given in Figure 7.

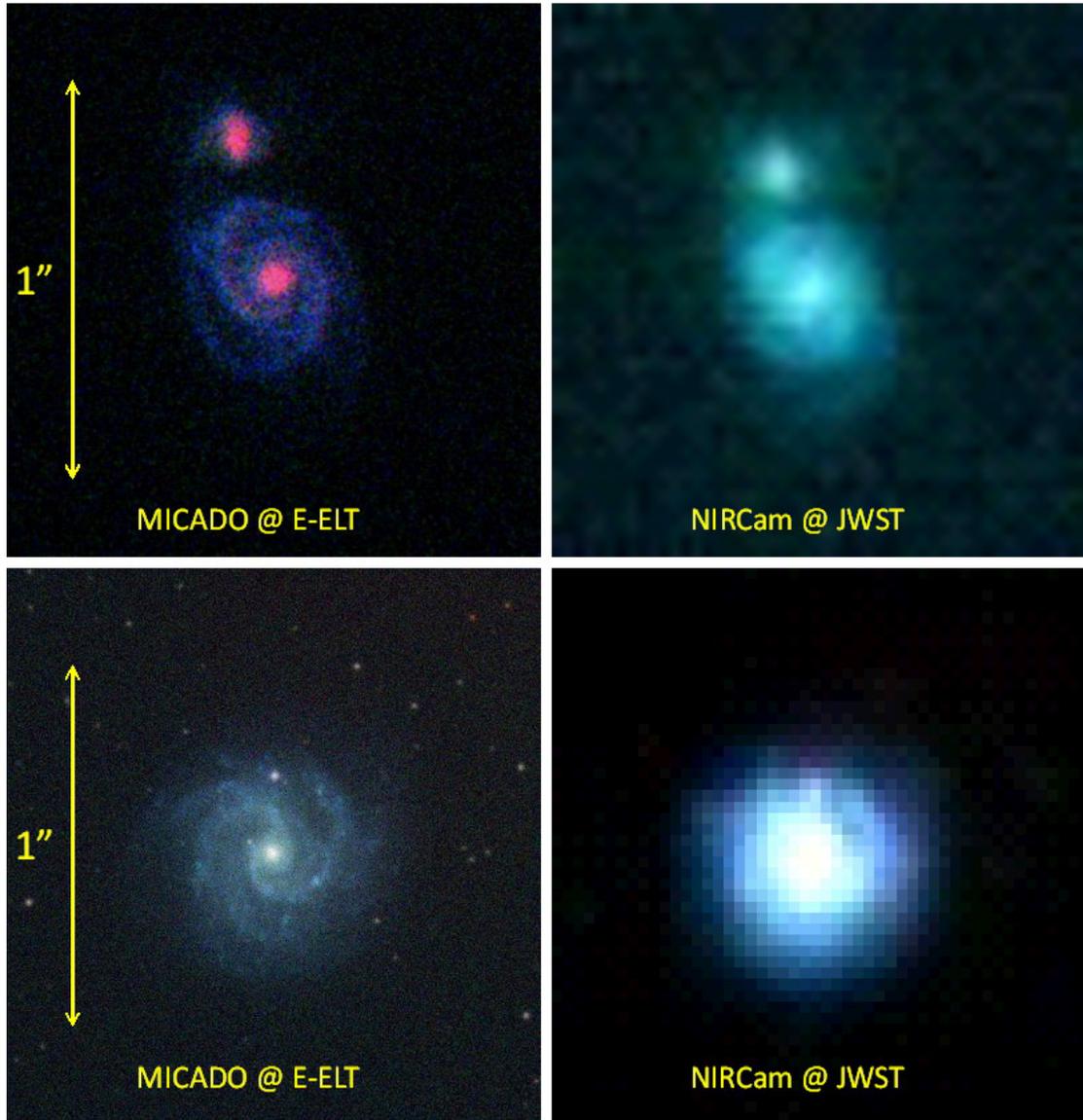


Figure 7. The simulated color (J,H and K) images of distant galaxies as imaged by MICADO @ ELT (left) in 5 hours and compared with what is expected using NIRCam at JWST (right). Simulation performed using templates of nearby galaxies after applying flux and color transformation to put the galaxy at redshift $z=1$ (bottom panels) and redshift $z=2$ (top panels).

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