

## GalSim Library Quick Reference

### 1. Overview

The GalSim Library provides a number of Python classes and methods for simulating astronomical images. The typical work flow will normally be something like the following:

- Construct a representation of your desired astronomical object as an instance of the `GObject` class. Multiple components can be combined or in combination using the special `Add` and `Convolve` `GObjects` — see Section 2.
- Apply transformations such as shears, shifts or magnification using the methods of the `GObject` — see Section 3.
- Draw the object into a GalSim `Image`, representing a postage stamp image of your astronomical object. This can be done using the `obj.draw(...)` or `obj.drawShoot(...)` methods carried by all `GObjects` for rendering images — see Section 3.
- Add noise to the `Image` using one of the GalSim random deviate classes — see Section 4.
- Add the postage stamp `Image` to a subsection of a larger `Image` instance, or to a list of `Image` instances multiple `Image` instances in preparation for output — see Section 5.
- Save the `Image(s)` to file in FITS (Flexible Image Transport System) format — see Section 5.

There are many examples of this workflow in the directory `GalSim/examples/`, showing most of the GalSim library in action, in the scripts named `demo1.py` – `demo8.py`.

We now provide a brief, reference description of the GalSim classes and methods which can be used in this workflow. Where possible in the following Sections this document has been hyperlinked to the online GalSim documentation generated by *doxygen* where a more detailed description can be found.

## 2. The GSOBJECTS

There are currently 12 types of `GSOBJECT`. The first ten listed are ‘simple’ or ‘atomic’ `GSOBJECT`s that can be initialized by providing values for their required or optional parameters; the last two are ‘compound’ classes used to represent combinations of `GSOBJECT`s. They are summarized in the following hyperlinked list, in the order in which the classes appear in `GalSim/galsim/base.py`:

- `Gaussian` — *a 2D Gaussian light profile.*
- `Moffat` — *a Moffat profile, used to approximate ground-based telescope PSFs.*
- `AtmosphericPSF` — *currently an image-based implementation of a Kolmogorov PSF (see below), but expected to evolve to use an image of a stochastically modelled atmospheric PSF in the near future.*
- `Airy` — *an Airy PSF for ideal diffraction through a circular aperture, with optional obscuration.*
- `Kolmogorov` — *the Kolmogorov PSF for long-exposure images through a turbulent atmosphere.*
- `OpticalPSF` — *a simple model for non-ideal (aberrated) propagation through circular or square apertures, with optional obscuration.*
- `Pixel` — *used for integrating light onto square or rectangular pixels.*
- `Sersic` — *the Sérsic family of galaxy light profiles.*
- `Exponential` — *the Exponential galaxy disc profile, a Sérsic with index  $n = 1$ .*
- `DeVaucouleurs` — *the De Vaucouleurs galaxy bulge profile, a Sérsic with index  $n = 4$ .*
- `RealGalaxy` — *models galaxies using real data, including a correction for the original PSF. Requires the download of external data for full functionality.*
- `Add` — *a compound object used for summing multiple `GSOBJECT`s.*
- `Convolve` — *a compound object used for convolving multiple `GSOBJECT`s.*

For more information and initialization details for each `GSOBJECT`, the Python docstring for each class is available by typing

```
>>> print galsim.<GSOBJECT_name>.__doc__
```

within the Python interpreter. Alternatively follow the hyperlinks on the class names above to view the *doxygen* documentation based on the Python docstrings.

### 3. Important GSOBJECT methods

A number of methods are shared by all the GSOBJECTs of Section 2, and are also to be found in `GalSim/galsim/base.py` within the definition of the GSOBJECT base class. In what follows, we assume that a GSOBJECT labelled `obj` has been instantiated using one of the calls described in the documentation linked above. For example,

```
>>> obj = galsim.Sersic(n=3.5, half_light_radius=1.743).
```

Some of the most important and commonly-used methods for such an instance are:

- `obj.copy()` — *return a copy of the GSOBJECT.*
- `obj.getFlux()` — *get the flux of the GSOBJECT.*
- `obj.scaleFlux(flux_ratio)` — *multiply the flux of the GSOBJECT by flux\_ratio.*
- `obj.setFlux(flux)` — *set the flux of the GSOBJECT to flux.*
- `obj.applyDilation(scale)` — *change of the linear size of the GSOBJECT by a factor scale, conserving flux.*
- `obj.applyMagnification(scale)` — *dilate linear size by scale and multiply total flux by scale<sup>2</sup>, conserving surface brightness.*
- `obj.applyShear(*args, **kwargs)` — *apply a shear to the GSOBJECT, handling a number of different input conventions (see also Ellipse; Section 6).*
- `obj.applyRotation(theta)` — *apply a rotation of theta (positive direction anti-clockwise) to the GSOBJECT, where theta is a galsim.Angle instance (see Section 6).*
- `obj.applyShift(dx, dy)` — *apply a (dx, dy) position shift to the GSOBJECT centroid.*
- `obj.draw(...)` — *draw an image of the GSOBJECT using Discrete Fourier Transforms and interpolation to perform the image rendering.*
- `obj.drawShoot(...)` — *draw an image of the GSOBJECT by shooting a finite number of photons to perform the image rendering. The resulting image therefore contains stochastic noise, but the rendering is otherwise very close to exact.*

Once again, for more information regarding each GSOBJECT method, the Python docstring is available

```
>>> print obj.<method_name>.__doc__
```

within the Python interpreter. Alternatively follow the hyperlinks on the class names above to view the *doxygen* documentation based on the Python docstrings. You will see that many of the GSOBJECT instances also have their own specialized methods, often for retrieving parameter values. Examples are `obj.getSigma()` for the Gaussian or `obj.getHalfLightRadius()` for many of the GSOBJECTs.

#### 4. Random deviate classes and methods

A short summary of the 8 random deviates currently implemented in GalSim, with a short description of their distributions:

- `UniformDeviate` — *uniform distribution in the interval  $[0, 1)$ .*
- `GaussianDeviate` — *Gaussian distribution with mean and standard deviation  $\sigma$ .*
- `BinomialDeviate` — *Binomial distribution for  $N$  trials each of probability  $p$ .*
- `PoissonDeviate` — *Poisson distribution with a single mean rate.*
- `CCDNoise` — *a basic detector noise model, parameterized by gain and read\_noise.*
- `WeibullDeviate` — *Weibull distribution family (includes Rayleigh and Exponential) with shape parameters  $a$  and  $b$ .*
- `GammaDeviate` — *Gamma distribution with parameters  $\alpha$  and  $\beta$ .*
- `Chi2Deviate` —  *$\chi^2$  distribution with degrees-of-freedom parameter  $n$ .*

Unfortunately the random deviate classes are not yet fully integrated within the *doxygen* documentation, due to their being C++ with compiled Python wrappers. This means that the class names above and methods below are not yet hyperlinked.

However, the full docstrings are available in `galsim/random.py`, so please refer there for more information, or type

```
>>> print galsim.<RandomDeviate_name>.__doc__
```

within the Python interpreter.

We now illustrate the most commonly-used methods of the random deviates, assuming that some random deviate instance `dev` has been instantiated, for example by

```
>>> dev = galsim.GaussianDeviate(sigma=3.9, mean=50.).
```

The two most important and commonly-used methods for such an instance are:

- `dev.applyTo(image)` — *adds a random number, distributed according to the distribution represented by `dev`, to each element in in a supplied `Image` instance `image` (see Section 5).*
- `dev()` — *returns a new random number drawn from the distribution represented by `dev`.*

## 5. Image classes and methods

The GalSim Image classes store array data, along with a figure for the pixel separation in physical units and image bounds information (origin, extent). The ImageView provides a mutable view into Image instance data, and ConstImageView an immutable view into Image instance data. The full docstrings are available in `galsim/image.py` with a description of the differences between these fundamental types.

They are used to store the rendered output of the GSOBJECT `obj.draw(...)` and `obj.drawShoot(...)` methods. They can also be operated on to add stochastic noise simulating real astronomical images (see Section 4), and have methods for writing to FITS format output.

There are four types of GalSim Image, one for each of four supported array data types:

- `ImageS`; `ImageViewS`; `ConstImageViewS` — *for short integers (typically 16 bit).*
- `ImageI`; `ImageViewI`; `ConstImageViewI` — *for integers (typically 32 bit).*
- `ImageF`; `ImageViewF`; `ConstImageViewF` — *for single precision (typically 32 bit) floats.*
- `ImageD`; `ImageViewD`; `ConstImageViewD` — *for double precision (typically 64 bit) floats.*

Unfortunately the Image classes are not yet fully integrated within the *doxygen* documentation, due to their being in C++ with compiled Python wrappers. This means that the class names above and methods below are not hyperlinked.

However, the full docstrings are available in `galsim/image.py`, so please refer there for more information, or type

```
>>> print galsim.<ImageName>.__doc__
```

within the Python interpreter.

We now illustrate the most commonly-used methods of Image class instances. We will assume that some image `img` has been instantiated, for example by

```
im = obj.draw(dx=1.).
```

The most important and commonly-used methods for such an instance are:

- `img.addNoise(dev)` — (see `galsim/noise.py`) *this adds stochastic noise, distributed as represented by the random deviate instance dev, to each element of the data array in img. This therefore has the same effect as dev.applyTo(img) (see Section 4).*
- `img.write(image, fits, ...)` — (see `galsim/fits.py`) *write the image to a FITS file or object as determined by the fits input parameter.*

- `img.writeMulti(image_list, fits, ...)` — (see `galsim/fits.py`) *write multiple images stored in a Python list object `image_list` to a Multi-Extension FITS file or object as determined by the `fits` input parameter.*
- `img.writeCube(image_list, fits, ...)` — (see `galsim/fits.py`) *write multiple images stored in a Python list object `image_list` to a three-dimensional FITS datacube object as determined by the `fits` input parameter.*

## 6. Miscellaneous classes and methods

- `Angle` — TODO: Find a good description of the working of the `Angle` class and put it here.
- `Ellipse` — (see `galsim/ellipse.py`) class to represent ellipses and thus ellipse-type transformations. The class can be initialized using a variety of differing parameter conventions.