ScopeSim Documentation

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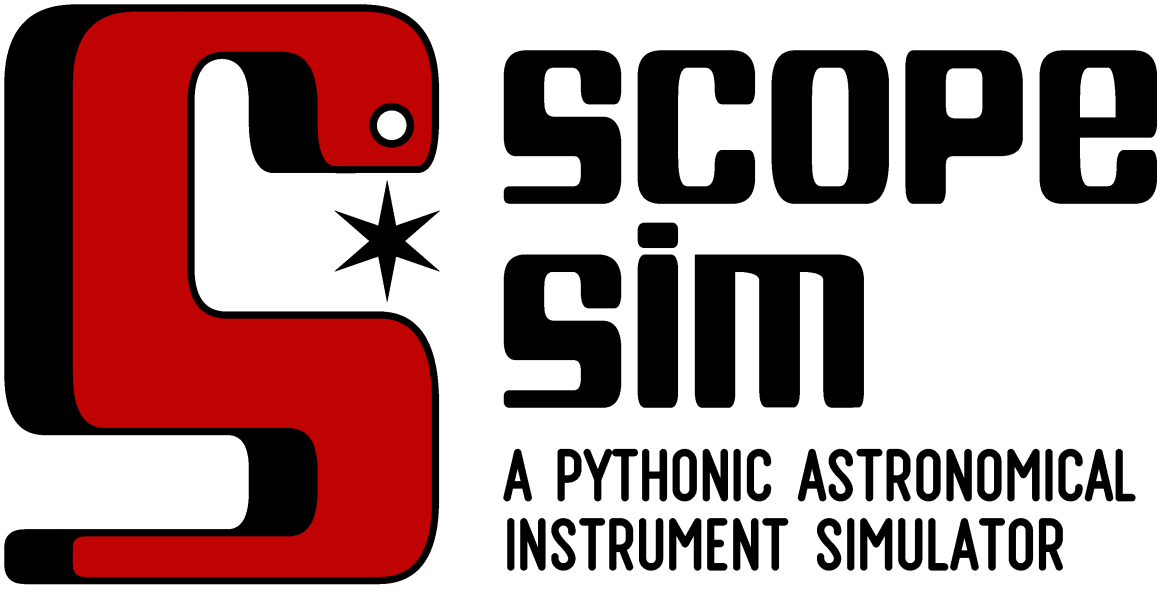
CONTENTS:



An attempt at creating a common pythonic framework for telescope instrument data simulators.

ScopeSim is on pip:

```
pip install scopesim
```

ScopeSim templates provides templates for creating on-sky sources:

```
pip install scopesim_templates
```

Warning: July 2022: The downloadable content server was retired and the data migrated to a new server.

ScopeSim v0.5.1 and above have been redirected to a new server URL.

For older verions, please either upgrade to the latest version (`pip install --upgrade scopesim`), or follow these instructions to update the server URL in the config file.

Note: For instrument specific guides, please see the IRDB

A basic simulation would look something like this:

[ ]:
```
from matplotlib import pyplot as plt
from matplotlib.colors import LogNorm

import scopesim as sim
from scopesim.source import source_templates as st

src = st.star_field(n=100,
                    mmax=15,      # [mag]
                    mmin=20,
                    width=200)    # [arcsec]
```

(continues on next page)

(continued from previous page)

```
opt = sim.load_example_optical_train()
opt.cmds["!OBS.dit"] = 60          # [s]
opt.cmds["!OBS.ndit"] = 10

opt.observe(src)
hdulist = opt.readout()[0]

plt.figure(figsize=(10,8))
plt.imshow(hdulist[1].data, norm=LogNorm(vmin=1))
plt.colorbar()
```

CHAPTER

ONE

CODE BREAKDOWN

Let's break this down a bit.

There are three major components of any simulation workflow:

1. the target description,
2. the telescope/instrument model, and
3. the observation.

For the target description we are using the ScopeSim internal template functions from `scopesim.source.source_templates`, however many more dedicated science related templates are available in the external python package ScopeSim-Templates

Here we create a field of 100 A0V stars with Vega magnitudes between V=15 and V=20 within a box of 200 arcsec:

[ ]:
```
src = st.star_field(n=100,
                    mmax=15,      # [mag]
                    mmin=20,
                    width=200)    # [arcsec]
```

Next we load the sample optical train object from ScopeSim.

Normally we will want to use an actual instrument. Dedicated documentation for real telescope+instrument systems can be found in the documentation sections of the individual instruments in the Instrument Reference Database (IRDB) documentation

For real instruments loading the optical system generally follows a different pattern:

```
cmd = sim.UserCommands(use_instrument="instrument_name", set_modes=["mode_1", "mode_2"])
opt = sim.OpticalTrain(cmds)
```

Once we have loaded the instrument, we can set the observation parameters by accessing the internal commands dictionary:

[ ]:
```
opt = sim.load_example_optical_train(set_modes=["imaging"])
opt.cmds["!OBS.dit"] = 60         # [s]
opt.cmds["!OBS.ndit"] = 10
```

Finally we observe the target source and readout the detectors.

What is returned (`hdulist`) is an `astropy.fits.HDUList` object which can be saved to disk in the standard way, or manipulated in a python session.

[ ]:
```
opt.observe(src)
hdulist = opt.readout()[0]
```

CHAPTER

TWO

TIPS AND TRICKS

2.1 Focal plane images

Intermediate frames of the focal plane image without the noise proerties can be accessed by looking inside the optical train object and accessing the first image plane:

[ ]:
```
noiseless_image = opt.image_planes[0].data
```

2.2 Turning optical effects on or off

All effects modelled by the optical train can be listed with the `.effects` attribute:

[ ]:
```
opt.effects
```

These can be turned on or off by using their name and the `.include` attribute:

[ ]:
```
opt["detector_linearity"].include = False
```

2.3 Listing available modes and filters

The list of observing modes can be found by using the `.modes` attribute of the commands objects:

[ ]:
```
opt.cmds.modes
```

The names of included filters can be found in the filter effect. Use the name of the filter object from the table above to list these:

[ ]:
```
opt["filter_wheel"].filters
```

2.4 Setting observation sequence

Although this could be different for some instruments, most instruments use the `exptime = ndit * dit` format. `ndit`and `dit` are generally accessible in the top level `!OBS` dictionary of the command object in the optical train.

[ ]:
```
opt.cmds["!OBS.dit"] = 60          # [s]
opt.cmds["!OBS.ndit"] = 10
```

2.5 Listing and changing simulation parameters

The command dictionary inside the optical system contains all the necessary paramters.

[ ]:
```
opt.cmds
```

The command object is a series of nested dictionaries that can be accessed using the `!-string` format:

```
opt.cmds["!<alias>.<param>"]
opt.cmds["!<alias>.<sub_dict>.<param>"]
```

For example, setting the atmospheric background level is achieved thusly:

[ ]:
```
opt.cmds["!ATMO.background.filter_name"] = "K"
opt.cmds["!ATMO.background.value"] = 13.6
```

CHAPTER

THREE

MORE INFORMATION

For more information on how to use ScopeSim be see:

- *Use Examples*
- Instrument Specific Documentation
- Effect data formats
- **`Setting up a custom instrument <>`__**

CHAPTER

FOUR

CONTACT

- For bugs, please add an issue to the github repo
- For enquiries on implementing your own instrument package, please drop us a line at astar.astro@univie.ac.at or kieran.leschinski@univie.ac.at

CHAPTER

FIVE

EXAMPLES

5.1 1: A quick use case for MICADO at the ELT

5.1.1 A brief introduction into using ScopeSim to observe a cluster in the LMC

This is a step-by-step guide. The complete script can be found at the bottom of this page/notebook.

First set up all relevant imports:

[1]:
```
import matplotlib.pyplot as plt
from matplotlib.colors import LogNorm
%matplotlib inline

import scopesim as sim
import scopesim_templates as sim_tp
```

```
updating/loading 'index.yml'
Downloading https://scopesim.univie.ac.at/spextra/database/index.yml [Done]
updating/loading 'default_filters.yml'
Downloading https://scopesim.univie.ac.at/spextra/database/default_filters.yml [Done]
updating/loading 'default_spectra.yml'
Downloading https://scopesim.univie.ac.at/spextra/database/default_spectra.yml [Done]
updating/loading 'default_curves.yml'
Downloading https://scopesim.univie.ac.at/spextra/database/default_curves.yml [Done]
```

Scopesim works by using so-called instrument packages, which have to be downloaded separately. For normal use, you would set the package directory (a local folder path, `local_package_folder` in this example), download the required packages *once*, and then **remove the download command**.

[2]:
```
local_package_folder = "./inst_pkgs"
```

However, to be able to run this example on the *Readthedocs* page, we need to include a temporary directory.

Do not copy and run this code locally, it is **only** needed to set things up for *Readthedocs*!

[3]:
```
from tempfile import TemporaryDirectory
local_package_folder = TemporaryDirectory().name
```

Download the required instrument packages for an observation with MICADO at the ELT.

Again, you would only need to do this **once**, not every time you run the rest of the script, assuming you set a (permanent) instrument package folder.

[4]:
```
sim.rc.__config__["!SIM.file.local_packages_path"] = local_package_folder
sim.download_packages(["Armazones", "ELT", "MORFEO", "MICADO"])
```

```
astar.scopesim.server.database - Gathering information from server ...
astar.scopesim.server.database - Connection successful, starting download ...
```

```
Downloading Armazones: 100%|| 74.3k/74.3k [00:00<00:00, 635kB/s]
Extracting  Armazones: 100%|| 10/10 [00:00<00:00, 3005.81it/s]
Downloading ELT      : 100%|| 53.4k/53.4k [00:00<00:00, 33.8MB/s]
Extracting  ELT      : 100%|| 16/16 [00:00<00:00, 5361.85it/s]
Downloading MORFEO   : 100%|| 1.38M/1.38M [00:02<00:00, 563kB/s]
Extracting  MORFEO   : 100%|| 12/12 [00:00<00:00, 951.36it/s]
Downloading MICADO   : 100%|| 14.4M/14.4M [00:27<00:00, 550kB/s]
Extracting  MICADO   : 100%|| 121/121 [00:00<00:00, 865.23it/s]
```

[4]:
```
[PosixPath('/tmp/tmps6zj23ku/Armazones.zip'),
 PosixPath('/tmp/tmps6zj23ku/ELT.zip'),
 PosixPath('/tmp/tmps6zj23ku/MORFEO.zip'),
 PosixPath('/tmp/tmps6zj23ku/MICADO.zip')]
```

Now, create a star cluster using the `scopesim_templates` package. You can ignore the output that is sometimes printed. The `seed` argument is used to control the random number generation that creates the stars in the cluster. If this number is kept the same, the output will be consistent with each run, otherwise the position and brightness of the stars is randomised every time.

[5]:
```
cluster = sim_tp.stellar.clusters.cluster(mass=1000,          # Msun
                                          distance=50000,     # parsec
                                          core_radius=0.3,    # parsec
                                          seed=9002)
```

```
imf - sample_imf: Setting maximum allowed mass to 1000
imf - sample_imf: Loop 0 added 1.26e+03 Msun to previous total of 0.00e+00 Msun
updating/loading 'filter_systems/etc/index.yml'
Downloading https://scopesim.univie.ac.at/spextra/database/filter_systems/etc/index.yml␣
↪[Done]
updating/loading 'filter_systems/etc/V.dat'
Downloading https://scopesim.univie.ac.at/spextra/database/filter_systems/etc/V.dat␣
↪[Done]
updating/loading 'libraries/ref/index.yml'
Downloading https://scopesim.univie.ac.at/spextra/database/libraries/ref/index.yml [Done]
updating/loading 'libraries/ref/vega.fits'
Downloading https://scopesim.univie.ac.at/spextra/database/libraries/ref/vega.fits [Done]
```

Next, make the MICADO optical system model with `OpticalTrain`. Observe the cluster `Source` object with the `.observe()` method and read out the MICADO detectors with `.readout()`. This may take a few moments on slower machines.

The resulting FITS file can either be returned as an `astropy.fits.HDUList` object, or saved to disk using the optional `filename` parameter

[6]:
```
micado = sim.OpticalTrain("MICADO")
micado.observe(cluster)
hdus = micado.readout()
# micado.readout(filename="TEST.fits")
```

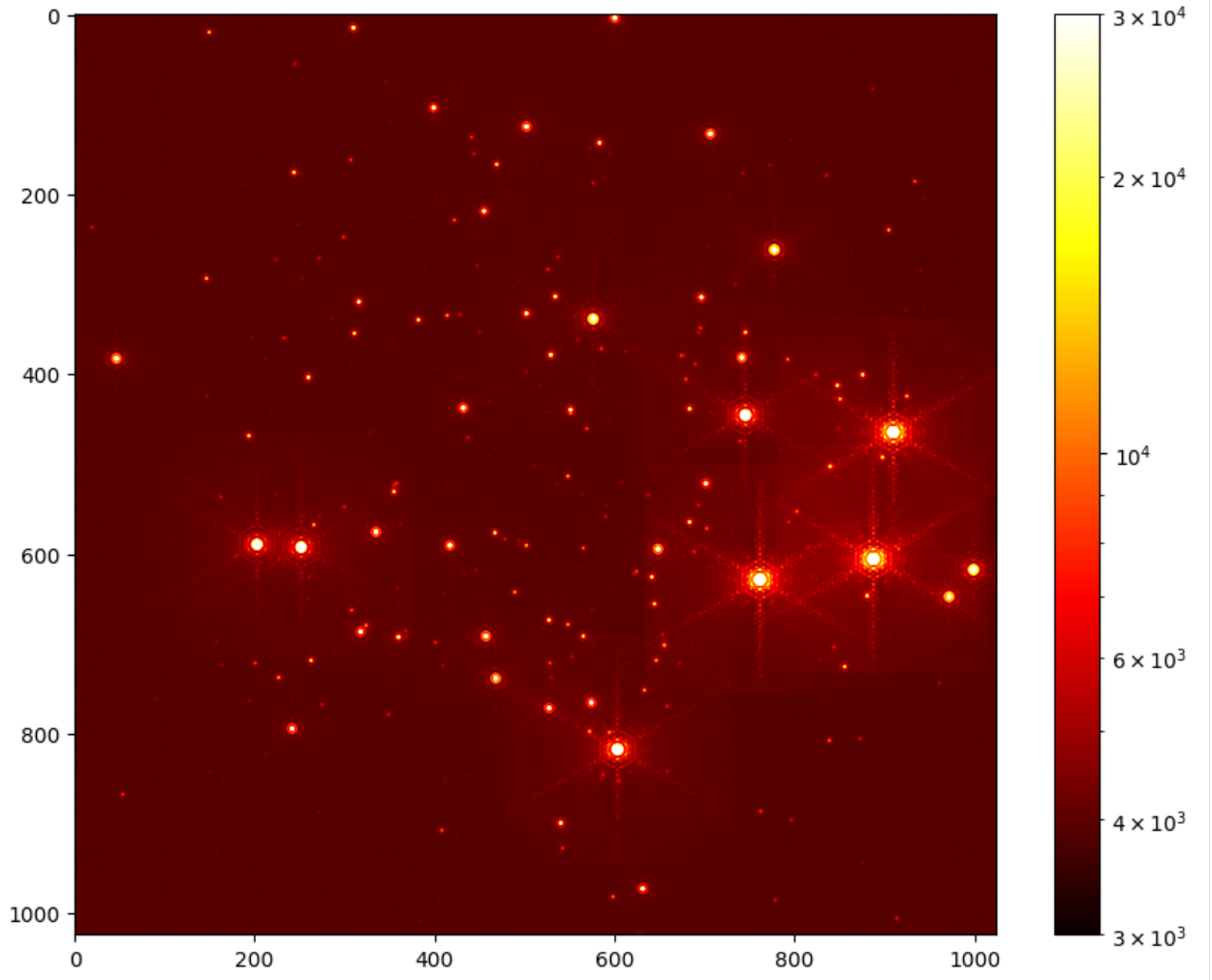
```
FOVs:   0%|          | 0/1 [00:00<?, ?it/s]
FOV effects:   0%|          | 0/2 [00:00<?, ?it/s]
FOV effects:  50%|     | 1/2 [00:00<00:00,  6.39it/s]
FOV effects: 100%|| 2/2 [00:00<00:00,  7.44it/s]
FOVs: 100%|| 1/1 [00:00<00:00,  1.94it/s]
Image Plane effects: 100%|| 1/1 [00:00<00:00, 5249.44it/s]
```

```
astar.scopesim.detector.detector_array - Extracting from 1 detectors...
```

Display the contents the first HDU

[7]:
```
plt.figure(figsize=(10,8))
plt.imshow(hdus[0][1].data, norm=LogNorm(vmax=3E4, vmin=3E3), cmap="hot")
plt.colorbar()
```

[7]:
```
<matplotlib.colorbar.Colorbar at 0x7f564cf88f50>
```



5.1.2 Complete script

Included below is the complete script for convenience, including the downloads, but not including the plotting.

[8]:
```
import scopesim as sim
import scopesim_templates as sim_tp

#sim.download_packages(["Armazones", "ELT", "MORFEO", "MICADO"])

cluster = sim_tp.stellar.clusters.cluster(mass=1000,          # Msun
                                          distance=50000,     # parsec
                                          core_radius=0.3,    # parsec
                                          seed=9002)

micado = sim.OpticalTrain("MICADO")
micado.observe(cluster)

hdus = micado.readout()
# micado.readout(filename="TEST.fits")
```

```
imf - sample_imf: Setting maximum allowed mass to 1000
imf - sample_imf: Loop 0 added 1.26e+03 Msun to previous total of 0.00e+00 Msun
```

```
 FOVs:   0%|          | 0/1 [00:00<?, ?it/s]
 FOV effects:   0%|          | 0/2 [00:00<?, ?it/s]
 FOV effects:  50%|     | 1/2 [00:00<00:00,  7.21it/s]
 FOV effects: 100%|| 2/2 [00:00<00:00,  7.79it/s]
 FOVs: 100%|| 1/1 [00:00<00:00,  2.04it/s]
 Image Plane effects: 100%|| 1/1 [00:00<00:00, 5184.55it/s]
```

```
astar.scopesim.detector.detector_array - Extracting from 1 detectors...
```

[ ]:
```
```

5.2 2: Observing the same object with multiple telescopes

A brief introduction into using ScopeSim to observe a cluster in the LMC using the 39m ELT and the 1.5m LFOA

This is a step-by-step guide. The complete script can be found at the bottom of this page/notebook.

First set up all relevant imports:

[1]:
```
import matplotlib.pyplot as plt
from matplotlib.colors import LogNorm
%matplotlib inline

import scopesim as sim
import scopesim_templates as sim_tp
```

Scopesim works by using so-called instrument packages, which have to be downloaded separately. For normal use, you would set the package directory (a local folder path, `local_package_folder` in this example), download the required packages *once*, and then **remove the download command**.

[2]:
```
local_package_folder = "./inst_pkgs"
```

However, to be able to run this example on the *Readthedocs* page, we need to include a temporary directory.

Do not copy and run this code locally, it is **only** needed to set things up for *Readthedocs*!

[3]:
```
from tempfile import TemporaryDirectory
local_package_folder = TemporaryDirectory().name
```

Download the packages for MICADO at the ELT and the viennese 1.5m telescope at the LFOA

Again, you would only need to do this **once**, not every time you run the rest of the script, assuming you set a (permanent) instrument package folder.

[4]:
```
sim.rc.__config__["!SIM.file.local_packages_path"] = local_package_folder
sim.download_packages(["Armazones", "ELT", "MICADO", "MORFEO", "LFOA"])
```

```
astar.scopesim.server.database - Gathering information from server ...
astar.scopesim.server.database - Connection successful, starting download ...
```

```
Downloading Armazones: 100%|| 74.3k/74.3k [00:00<00:00, 639kB/s]
Extracting  Armazones: 100%|| 10/10 [00:00<00:00, 3160.98it/s]
Downloading ELT      : 100%|| 53.4k/53.4k [00:00<00:00, 30.3MB/s]
Extracting  ELT      : 100%|| 16/16 [00:00<00:00, 5349.45it/s]
Downloading MICADO   : 100%|| 14.4M/14.4M [00:27<00:00, 551kB/s]
Extracting  MICADO   : 100%|| 121/121 [00:00<00:00, 853.91it/s]
Downloading MORFEO   : 100%|| 1.38M/1.38M [00:02<00:00, 563kB/s]
Extracting  MORFEO   : 100%|| 12/12 [00:00<00:00, 950.59it/s]
Downloading LFOA     : 100%|| 409k/409k [00:00<00:00, 595kB/s]
Extracting  LFOA     : 100%|| 45/45 [00:00<00:00, 3574.62it/s]
```

[4]:
```
[PosixPath('/tmp/tmp3fo279no/Armazones.zip'),
 PosixPath('/tmp/tmp3fo279no/ELT.zip'),
 PosixPath('/tmp/tmp3fo279no/MICADO.zip'),
 PosixPath('/tmp/tmp3fo279no/MORFEO.zip'),
 PosixPath('/tmp/tmp3fo279no/LFOA.zip')]
```

5.2.1 Create a star cluster `Source` object

Now, create a star cluster using the scopesim_templates package. You can ignore the output that is sometimes printed. The seed argument is used to control the random number generation that creates the stars in the cluster. If this number is kept the same, the output will be consistent with each run, otherwise the position and brightness of the stars is randomised every time.

[5]:
```
cluster = sim_tp.stellar.clusters.cluster(mass=10000,         # Msun
                                          distance=50000,     # parsec
                                          core_radius=2,      # parsec
                                          seed=9001)          # random seed
```

```
imf - sample_imf: Setting maximum allowed mass to 10000
imf - sample_imf: Loop 0 added 1.01e+04 Msun to previous total of 0.00e+00 Msun
```

5.2.2 Observe with the 1.5m telescope at the LFOA

|ee2d02a582174223b87ed988fd700bae|

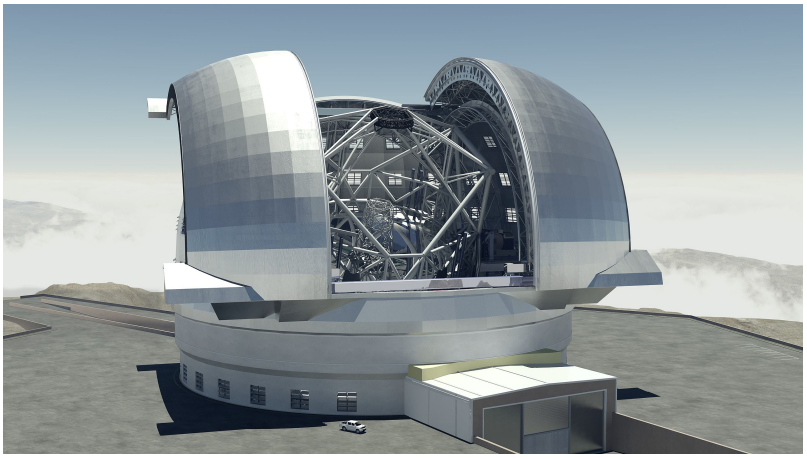
[6]:
```
lfoa = sim.OpticalTrain("LFOA")
lfoa.observe(cluster,
             properties={"!OBS.ndit": 10, "!OBS.ndit": 360},
             update=True)
hdus_lfoa = lfoa.readout()
```

```
 FOVs:   0%|          | 0/1 [00:00<?, ?it/s]
 FOV effects:   0%|          | 0/1 [00:00<?, ?it/s]
 FOV effects: 100%|| 1/1 [00:00<00:00,  1.85it/s]
 FOVs: 100%|| 1/1 [00:00<00:00,  1.13it/s]
 Image Plane effects: 0it [00:00, ?it/s]
```

```
astar.scopesim.detector.detector_array - Extracting from 1 detectors...
```

```
astar.scopesim.optics.optical_train - ERROR: Header update failed, data will be saved␣
↪with incomplete header. See stack trace for details.
Traceback (most recent call last):
  File "/home/docs/checkouts/readthedocs.org/user_builds/scopesim/checkouts/stable/
↪scopesim/optics/optical_train.py", line 386, in readout
    hdul = self.write_header(hdul)
           ^^^^^^^^^^^^^^^^^^^^^^^
  File "/home/docs/checkouts/readthedocs.org/user_builds/scopesim/checkouts/stable/
↪scopesim/optics/optical_train.py", line 408, in write_header
    pheader["INSTRUME"] = from_currsys("!OBS.instrument", self.cmds)
                          ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
  File "/home/docs/checkouts/readthedocs.org/user_builds/scopesim/checkouts/stable/
↪scopesim/utils.py", line 542, in from_currsys
    raise ValueError(f"{item} was not found in rc.__currsys__")
ValueError: !OBS.instrument was not found in rc.__currsys__
```

5.2.3 Observe the same `Source` with MICADO at the ELT



[7]:
```
micado = sim.OpticalTrain("MICADO")
micado.cmds["!OBS.dit"] = 10
micado.cmds["!OBS.ndit"] = 360
micado.update()

micado.observe(cluster)
hdus_micado = micado.readout()
```

```
FOVs:   0%|          | 0/1 [00:00<?, ?it/s]
FOV effects:   0%|          | 0/2 [00:00<?, ?it/s]
FOV effects:  50%|     | 1/2 [00:00<00:00,  7.86it/s]
FOV effects: 100%|| 2/2 [00:00<00:00,  8.08it/s]
FOVs: 100%|| 1/1 [00:00<00:00,  2.09it/s]
Image Plane effects: 100%|| 1/1 [00:00<00:00, 5140.08it/s]
```

```
astar.scopesim.detector.detector_array - Extracting from 1 detectors...
```

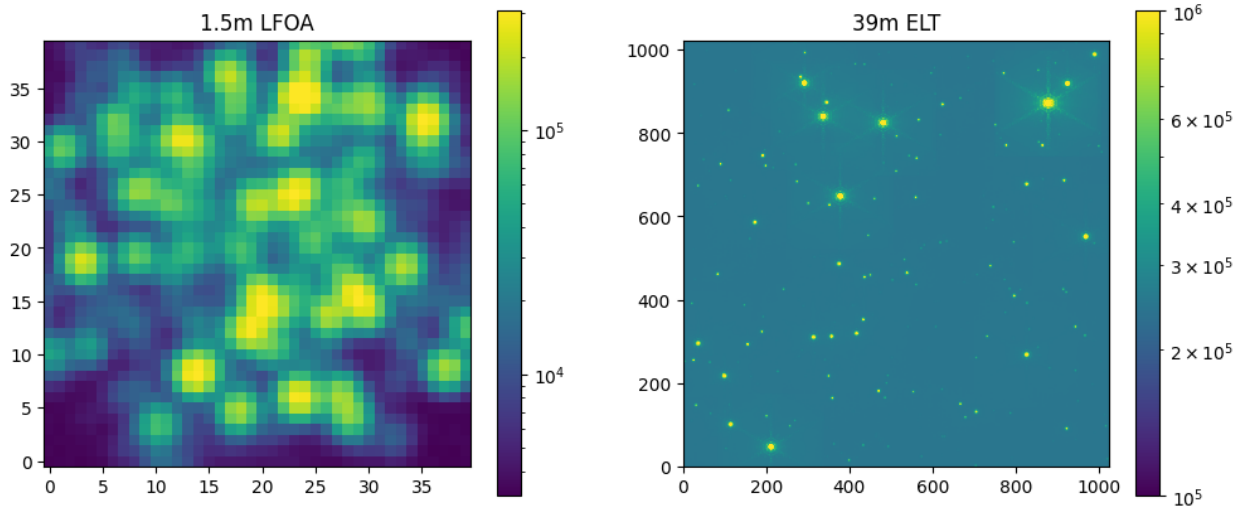
Plot up the results

[8]:
```
plt.figure(figsize=(12,5))

plt.subplot(121)
plt.imshow(hdus_lfoa[0][1].data[345:385, 525:565], norm=LogNorm(), origin="lower")
plt.colorbar()
plt.title("1.5m LFOA")

plt.subplot(122)
plt.imshow(hdus_micado[0][1].data, norm=LogNorm(vmax=1E6, vmin=1e5), origin="lower")
plt.colorbar()
plt.title("39m ELT")
```

[8]:
```
Text(0.5, 1.0, '39m ELT')
```



5.2.4 Complete script

Included below is the complete script for convenience, including the downloads, but not including the plotting.

[9]:
```
import scopesim as sim
import scopesim_templates as sim_tp

# sim.download_packages(["Armazones", "ELT", "MICADO", "MORFEO", "LFOA"])

cluster = sim_tp.stellar.clusters.cluster(mass=10000,        # Msun
                                          distance=50000,    # parsec
                                          core_radius=2,     # parsec
                                          seed=9001)         # random seed

lfoa = sim.OpticalTrain("LFOA")
lfoa.observe(cluster,
             properties={"!OBS.ndit": 10, "!OBS.ndit": 360},
             update=True)
hdus_lfoa = lfoa.readout()

micado = sim.OpticalTrain("MICADO")
micado.cmds["!OBS.dit"] = 10
micado.cmds["!OBS.ndit"] = 360
micado.update()

micado.observe(cluster)
hdus_micado = micado.readout()
```

```
imf - sample_imf: Setting maximum allowed mass to 10000
imf - sample_imf: Loop 0 added 1.01e+04 Msun to previous total of 0.00e+00 Msun
```

```
FOVs:   0%|          | 0/1 [00:00<?, ?it/s]
FOV effects:   0%|          | 0/1 [00:00<?, ?it/s]
FOV effects: 100%|| 1/1 [00:00<00:00,  2.00it/s]
FOVs: 100%|| 1/1 [00:00<00:00,  1.22it/s]
Image Plane effects: 0it [00:00, ?it/s]
```

```
astar.scopesim.detector.detector_array - Extracting from 1 detectors...
```

```
astar.scopesim.optics.optical_train - ERROR: Header update failed, data will be saved␣
↪with incomplete header. See stack trace for details.
Traceback (most recent call last):
  File "/home/docs/checkouts/readthedocs.org/user_builds/scopesim/checkouts/stable/
↪scopesim/optics/optical_train.py", line 386, in readout
    hdul = self.write_header(hdul)
           ^^^^^^^^^^^^^^^^^^^^^^^
  File "/home/docs/checkouts/readthedocs.org/user_builds/scopesim/checkouts/stable/
↪scopesim/optics/optical_train.py", line 408, in write_header
    pheader["INSTRUME"] = from_currsys("!OBS.instrument", self.cmds)
                          ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
  File "/home/docs/checkouts/readthedocs.org/user_builds/scopesim/checkouts/stable/
↪scopesim/utils.py", line 542, in from_currsys
    raise ValueError(f"{item} was not found in rc.__currsys__")
```

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```
ValueError: !OBS.instrument was not found in rc.__currsys__
```

```
 FOVs:   0%|          | 0/1 [00:00<?, ?it/s]
 FOV effects:   0%|          | 0/2 [00:00<?, ?it/s]
 FOV effects:  50%|     | 1/2 [00:00<00:00,  7.67it/s]
 FOV effects: 100%|| 2/2 [00:00<00:00,  8.56it/s]
 FOVs: 100%|| 1/1 [00:00<00:00,  2.15it/s]
 Image Plane effects: 100%|| 1/1 [00:00<00:00, 5622.39it/s]
```

```
astar.scopesim.detector.detector_array - Extracting from 1 detectors...
```

[ ]:

5.3 3: Writing and including custom Effects

In this tutorial, we will load the model of MICADO (including Armazones, ELT, MORFEO) and then turn off all effect that modify the spatial extent of the stars. The purpose here is to see in detail what happens to the **distribution of the stars flux on a sub-pixel level** when we add a plug-in astrometric Effect to the optical system.

For real simulation, we will obviously leave all normal MICADO effects turned on, while still adding the plug-in Effect. Hopefully this tutorial will serve as a refernce for those who want to see **how to create Plug-ins** and how to manipulate the effects in the MICADO optical train model.

5.3.1 Create and optical model for MICADO and the ELT

[1]:
```
from tempfile import TemporaryDirectory

import numpy as np
import matplotlib.pyplot as plt
from matplotlib.colors import LogNorm

import scopesim as sim
from scopesim_templates.stellar import stars, star_grid
```

Scopesim works by using so-called instrument packages, which have to be downloaded separately. For normal use, you would set the package directory (a local folder path, `local_package_folder` in this example), download the required packages *once*, and then **remove the download command**.

[2]:
```
local_package_folder = "./inst_pkgs"
```

However, to be able to run this example on the *Readthedocs* page, we need to include a temporary directory.

Do not copy and run this code locally, it is **only** needed to set things up for *Readthedocs*!

[3]:
```
from tempfile import TemporaryDirectory
local_package_folder = TemporaryDirectory().name
```

Download the required instrument packages for an observation with MICADO at the ELT.

Again, you would only need to do this **once**, not every time you run the rest of the script, assuming you set a (permanent) instrument package folder.

[4]:
```
sim.download_packages(["Armazones", "ELT", "MICADO", "MORFEO"])
```

```
astar.scopesim.server.database - Gathering information from server ...
astar.scopesim.server.database - Connection successful, starting download ...
```

```
Downloading Armazones: 100%|| 74.3k/74.3k [00:00<00:00, 644kB/s]
Extracting  Armazones: 100%|| 10/10 [00:00<00:00, 3396.20it/s]
Downloading ELT      : 100%|| 53.4k/53.4k [00:00<00:00, 38.7MB/s]
Extracting  ELT      : 100%|| 16/16 [00:00<00:00, 5322.30it/s]
Downloading MICADO   : 100%|| 14.4M/14.4M [00:27<00:00, 550kB/s]
Extracting  MICADO   : 100%|| 121/121 [00:00<00:00, 870.98it/s]
Downloading MORFEO   : 100%|| 1.38M/1.38M [00:02<00:00, 562kB/s]
Extracting  MORFEO   : 100%|| 12/12 [00:00<00:00, 953.38it/s]
```

[4]:
```
[PosixPath('/home/docs/checkouts/readthedocs.org/user_builds/scopesim/checkouts/stable/
↪docs/source/examples/inst_pkgs/Armazones.zip'),
 PosixPath('/home/docs/checkouts/readthedocs.org/user_builds/scopesim/checkouts/stable/
↪docs/source/examples/inst_pkgs/ELT.zip'),
 PosixPath('/home/docs/checkouts/readthedocs.org/user_builds/scopesim/checkouts/stable/
↪docs/source/examples/inst_pkgs/MICADO.zip'),
 PosixPath('/home/docs/checkouts/readthedocs.org/user_builds/scopesim/checkouts/stable/
↪docs/source/examples/inst_pkgs/MORFEO.zip')]
```

We can see which Effects are already included by calling `micado.effects`:

[5]:
```
cmd = sim.UserCommands(use_instrument="MICADO", set_modes=["SCAO", "IMG_1.5mas"])
micado = sim.OpticalTrain(cmd)

micado.effects
```

[5]:
```
<Table length=23>
   element              name                       class              included
    str13              str23                       str31                bool
------------ ---------------------- ------------------------------ --------
    armazones      skycalc_atmosphere                SkycalcTERCurve     True
          ELT    telescope_reflection                    SurfaceList     True
       MICADO  micado_static_surfaces                    SurfaceList     True
       MICADO        micado_ncpas_psf         NonCommonPathAberration     True
       MICADO filter_wheel_1 : [open]                    FilterWheel     True
       MICADO   filter_wheel_2 : [Ks]                    FilterWheel     True
       MICADO    pupil_wheel : [open]                    FilterWheel     True
   MICADO_DET     full_detector_array                  DetectorList    False
   MICADO_DET         detector_window                DetectorWindow     True
   MICADO_DET                qe_curve          QuantumEfficiencyCurve     True
          ...                     ...                             ...      ...
   MICADO_DET      detector_linearity                 LinearityCurve     True
   MICADO_DET border_reference_pixels           ReferencePixelBorder     True
   MICADO_DET           readout_noise        PoorMansHxRGReadoutNoise     True
   MICADO_DET    source_fits_keywords   SourceDescriptionFitsKeywords    False
   MICADO_DET     extra_fits_keywords               ExtraFitsKeywords     True
   default_ro               relay_psf                FieldConstantPSF     True
   default_ro      relay_surface_list                    SurfaceList     True
   default_ro  extra_fits_keywords_ro               ExtraFitsKeywords     True
MICADO_IMG_HR        zoom_mirror_list                    SurfaceList     True
MICADO_IMG_HR     micado_adc_3D_shift AtmosphericDispersionCorrection    False
```

Now we turn off all `Effects` that cause spatial aberrations:

[6]:
```
for effect_name in ["full_detector_array", "micado_adc_3D_shift",
                    "micado_ncpas_psf", "relay_psf"]:
    micado[effect_name].include = False
    print(micado[effect_name])
```

```
DetectorList: "full_detector_array"
AtmosphericDispersionCorrection: "micado_adc_3D_shift"
NonCommonPathAberration: "micado_ncpas_psf"
FieldConstantPSF: "relay_psf"
```

The normal detector window is set to 1024 pixels square. Let's reduce the size of the detector readout window:

[7]:
```
micado["detector_window"].data["x_cen"] = 0          # [mm] distance from optical axis␣
↪on the focal plane
micado["detector_window"].data["y_cen"] = 0
micado["detector_window"].data["x_size"] = 64          # [pixel] width of detector
micado["detector_window"].data["y_size"] = 64
```

By default ScopeSim works on the whole pixel level for saving computation time. However it is capable of integrating sub pixel shift. For this we need to turn on the sub-pixel mode:

[8]:
```
micado.cmds["!SIM.sub_pixel.flag"] = True
```

We can test what's happening by making a grid of stars and observing them:

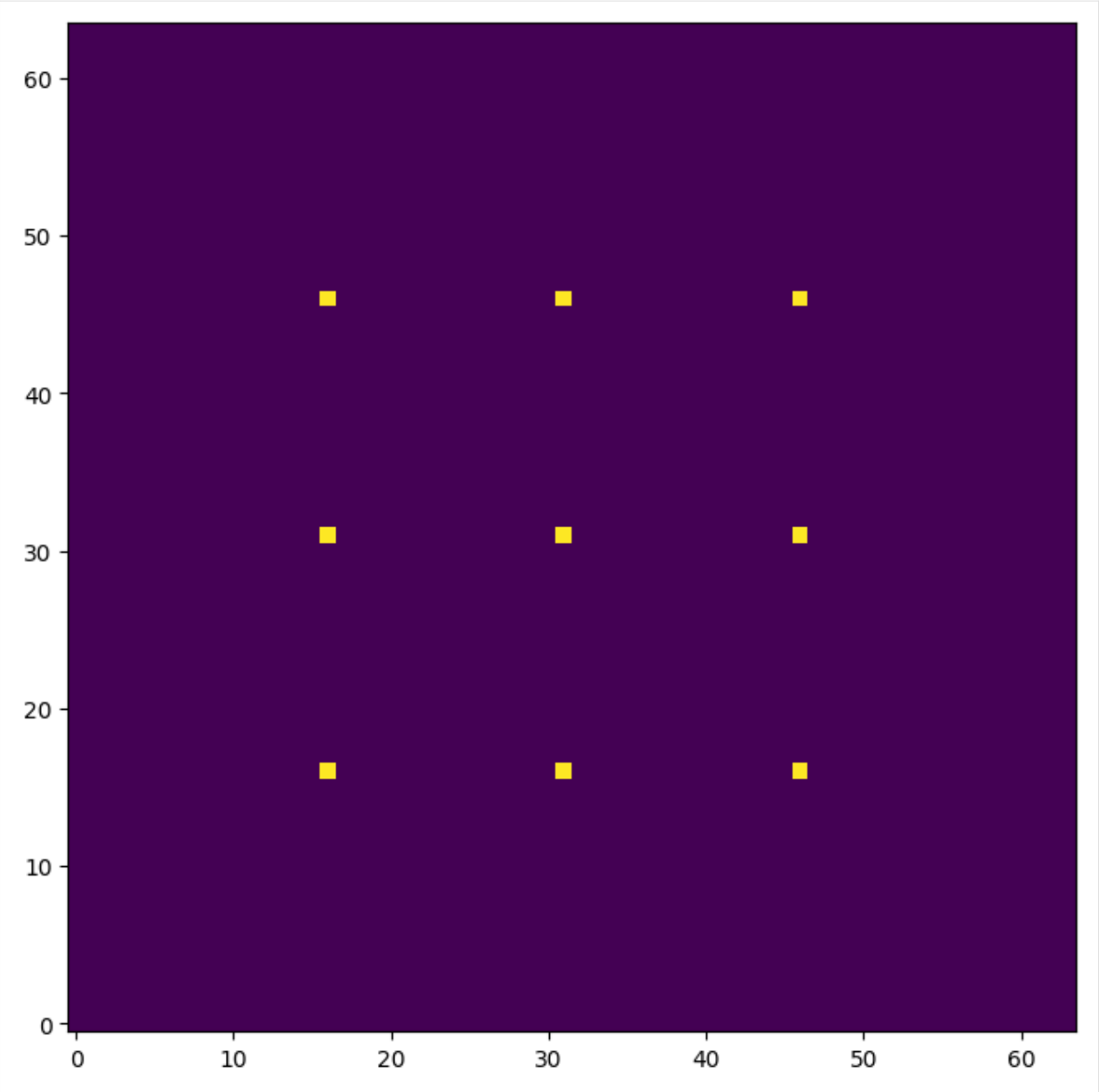
[9]:
```
src = star_grid(n=9, mmin=20, mmax=20.0001, separation=0.0015 * 15)
src.fields[0]["x"] -= 0.00075
src.fields[0]["y"] -= 0.00075

micado.observe(src, update=True)

plt.figure(figsize=(8,8))
plt.imshow(micado.image_planes[0].data, origin="lower")
```

```
FOVs:   0%|          | 0/1 [00:00<?, ?it/s]
FOV effects: 0it [00:00, ?it/s]
FOVs: 100%|| 1/1 [00:00<00:00, 14.44it/s]
Image Plane effects: 100%|| 1/1 [00:00<00:00, 5146.39it/s]
```

[9]:
```
<matplotlib.image.AxesImage at 0x7fdcdd7b3990>
```



[10]:
```
micado["detector_window"].data
```

[10]:
```
<Table length=1>
  id  x_cen y_cen x_size y_size angle  gain pixel_size
int64  str6  str6 str10  str11  int64 int64  float64
----- ----- ----- ------ ------ ----- ----- ----------
    0     0     0     64     64     0     1      0.015
```

5.3.2 Writing a custom Effect object

The following code snippet creates a new `Effect` class.

[11]:
```
import numpy as np
from astropy.table import Table

from scopesim.effects import Effect
from scopesim.base_classes import SourceBase


class PointSourceJitter(Effect):
    def __init__(self, **kwargs):
        super(PointSourceJitter, self).__init__(**kwargs)   # initialise the underlying␣
↪Effect class object
        self.meta["z_order"] = [500]                        # z_order number for knowing␣
↪when and how to apply the Effect
        self.meta["max_jitter"] = 0.001                     # [arcsec] - a parameter␣
↪needed by the effect
        self.meta.update(kwargs)                            # add any extra parameters␣
↪passed when initialising

    def apply_to(self, obj):                                # the function that does the␣
↪work
        if isinstance(obj, SourceBase):
            for field in obj.fields:
                if isinstance(field, Table):
                    dx, dy = 2 * (np.random.random(size=(2, len(field))) - 0.5)
                    field["x"] += dx * self.meta["max_jitter"]
                    field["y"] += dy * self.meta["max_jitter"]

        return obj
```

Lets break it down a bit (**THIS IS JUST A STEP-BY-STEP EXPLANATION OF THE CODE ABOVE, NOT SOMETHING NEW!**):

```
class PointSourceJitter(Effect):
    ...
```

Here we are subclassing the `Effect` object from ScopeSim. This has the basic functionality for reading in ASCII and FITS files, and for communicating with the `OpticsManager` class in ScopeSim.

The initialisation function looks like this:

```
def __init__(self, **kwargs):
    super(PointSourceJitter, self).__init__(**kwargs)   # initialise the underlying␣
↪Effect class object
    self.meta["z_order"] = [500]
```

Here we make sure to activate the underlying Effect object. The `z_order` keyword in the meta dictionary is used by ScopeSim to determine when and where this Effect should be applied during a simulations run. The exact z-order numbers are described in [insert link here].

The main function of any Effect is the `apply_to` method:

```
def apply_to(self, obj):
    if isinstance(obj, SourceBase):
        ...

    return obj
```

It should be noted that what is passed in via (`obj`) must be returned in the same format. The contents of the `obj` can change, but the `obj` object must be returned.

All the code which enacts the results of the physical effect are contained in this method. For example, if we are writing a redshifting Effect, we could write the code to shift the wavelength array of a `Source` object by `z+1` here.

There are 4 main classes that are cycled through during an observation run: * `SourceBase`: contains the original 2+1D distribtion of light, * `FieldOfViewBase`: contains a (quasi-)monochromatic cutout from the Source object, * `ImagePlaneBase`: contains the expectation flux image on the detector plane * `DetectorBase`: contains the electronic readout image

An `Effect` object can be applied to any number of objects based on one or more of these base classes. Just remember to segregate the base-class-specific code with `if` statements.

One further method should be mentioned: `def fov_grid()`. This method is used by `FOVManager` to estimate how many `FieldOfView` objects to generate in order to best simulation the observation. If your Effect object might alter this estimate, then you should include this method in your class. See the code base for further details.

Note: The `fov_grid` method will be depreciated in a future release of ScopeSim. It will most likely be replaced by a `FOVSetupBase` class that will be cycled through the `apply_to` function. However this is not yet 100% certain, so please bear with us.

5.3.3 Including a custom Effect

First we need to initialise an instance of the Effect object:

[12]:
```
jitter_effect = PointSourceJitter(max_jitter=0.001, name="random_jitter")
```

Then we can add it to the optical model:

[13]:
```
micado.optics_manager.add_effect(jitter_effect)

micado.effects
```

[13]:
```
<Table length=24>
   element              name                       class              included
    str13              str23                       str31                bool
------------ ---------------------- ------------------------------ --------
    armazones      skycalc_atmosphere                SkycalcTERCurve     True
    armazones           random_jitter               PointSourceJitter     True
          ELT    telescope_reflection                     SurfaceList     True
       MICADO  micado_static_surfaces                     SurfaceList     True
       MICADO        micado_ncpas_psf         NonCommonPathAberration    False
       MICADO filter_wheel_1 : [open]                     FilterWheel     True
       MICADO   filter_wheel_2 : [Ks]                     FilterWheel     True
       MICADO    pupil_wheel : [open]                     FilterWheel     True
   MICADO_DET     full_detector_array                   DetectorList    False
   MICADO_DET         detector_window                DetectorWindow     True
          ...                     ...                           ...      ...
```

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```
   MICADO_DET      detector_linearity                 LinearityCurve     True
   MICADO_DET border_reference_pixels            ReferencePixelBorder     True
   MICADO_DET           readout_noise        PoorMansHxRGReadoutNoise     True
   MICADO_DET    source_fits_keywords   SourceDescriptionFitsKeywords    False
   MICADO_DET     extra_fits_keywords               ExtraFitsKeywords     True
   default_ro               relay_psf                FieldConstantPSF    False
   default_ro      relay_surface_list                     SurfaceList     True
   default_ro  extra_fits_keywords_ro               ExtraFitsKeywords     True
MICADO_IMG_HR        zoom_mirror_list                     SurfaceList     True
MICADO_IMG_HR     micado_adc_3D_shift AtmosphericDispersionCorrection    False
```

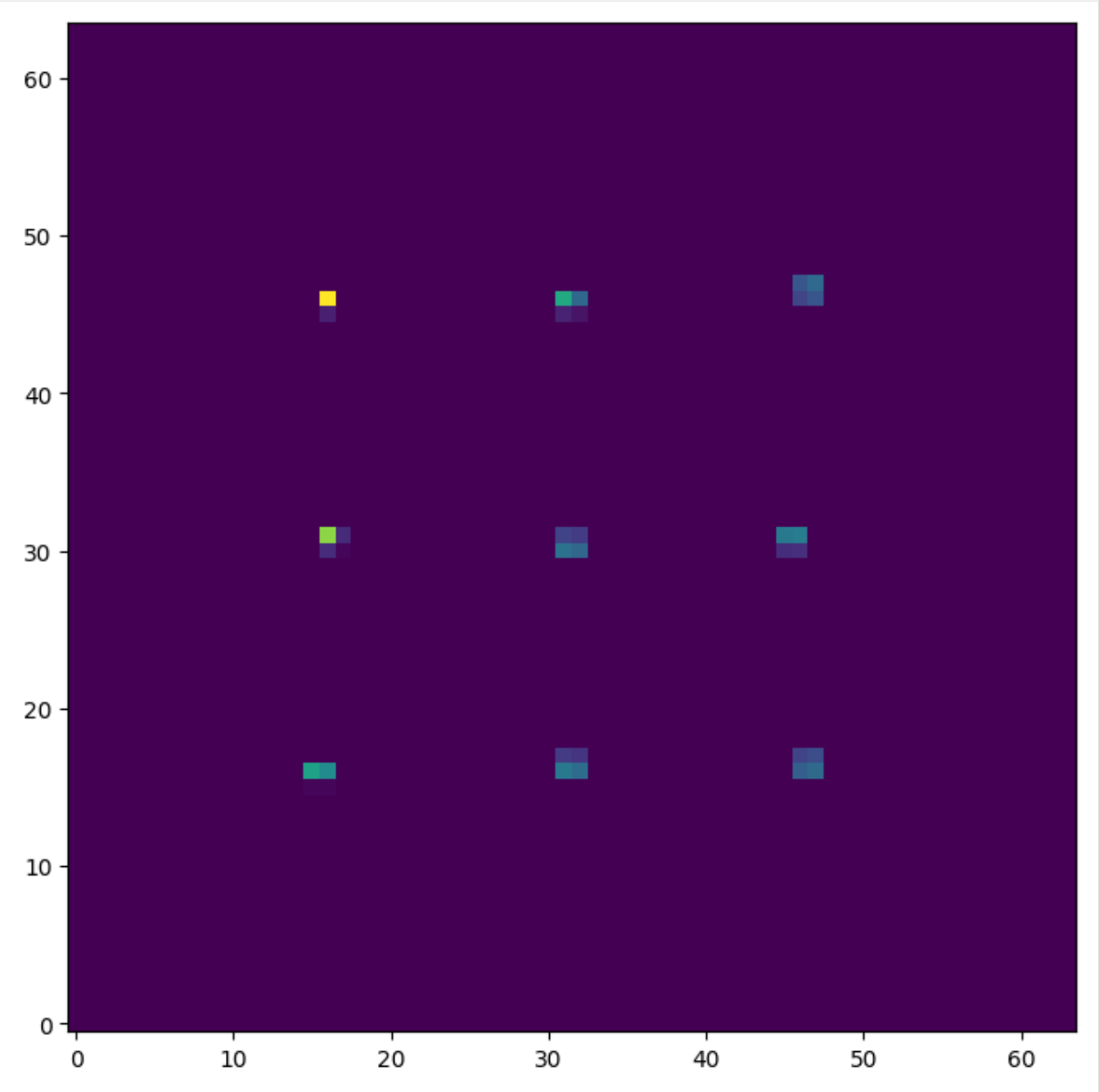
When we want to observe, we need to include the `update=True` flag so that the optical model is updated to include the instance of our new `Effect`:

[14]:
```
micado.observe(src, update=True)

plt.figure(figsize=(8,8))
plt.imshow(micado.image_planes[0].data, origin="lower")
```

```
FOVs:   0%|          | 0/1 [00:00<?, ?it/s]
FOV effects: 0it [00:00, ?it/s]
FOVs: 100%|| 1/1 [00:00<00:00, 14.40it/s]
Image Plane effects: 100%|| 1/1 [00:00<00:00, 5526.09it/s]
```

[14]:
```
<matplotlib.image.AxesImage at 0x7fdcdf480c90>
```



We can update the parameters of the object on-the-fly by accessing the meta dictionary:

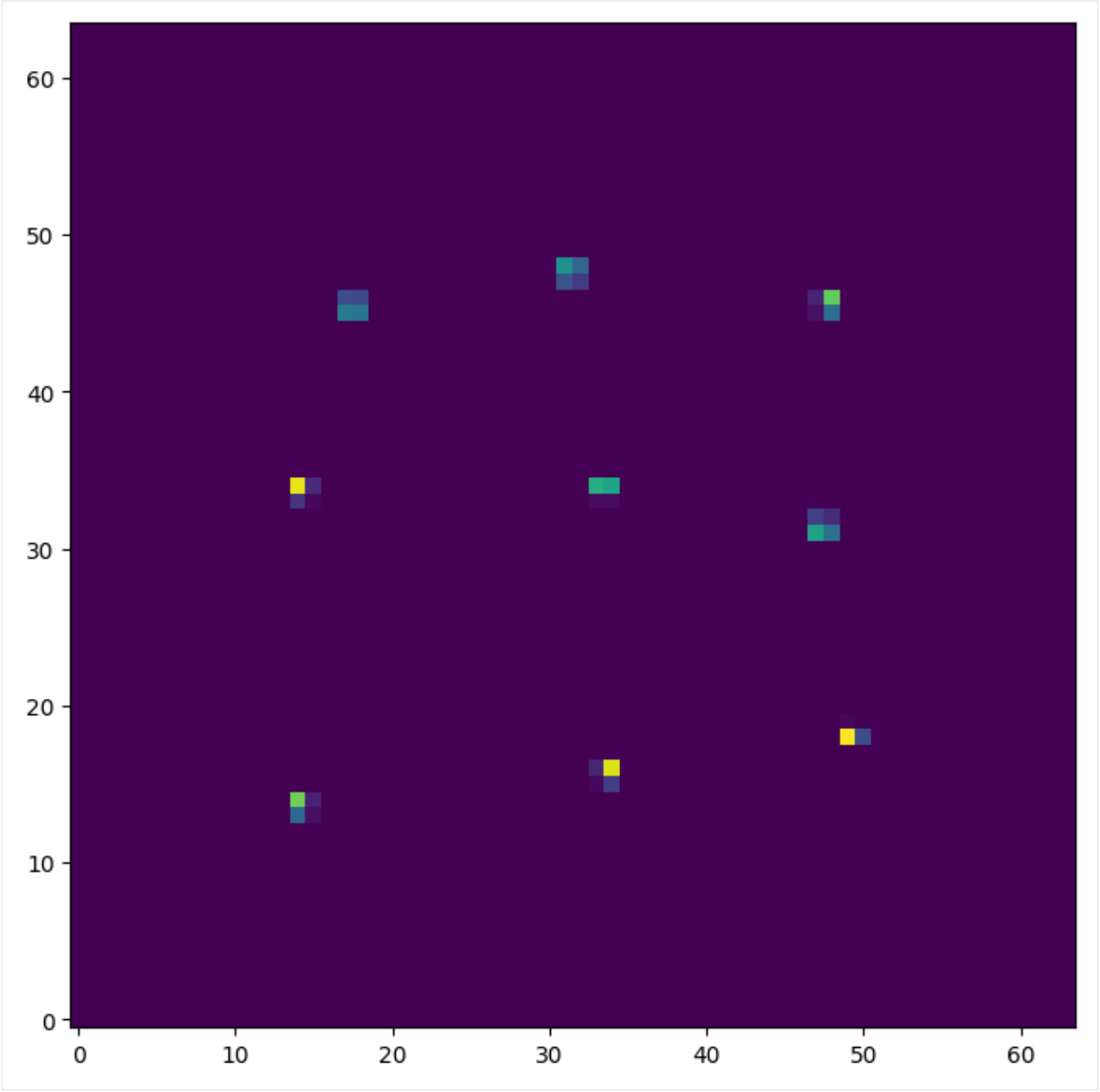
[15]:
```
micado["random_jitter"].meta["max_jitter"] = 0.005

micado.observe(src, update=True)

plt.figure(figsize=(8,8))
plt.imshow(micado.image_planes[0].data, origin="lower")
```

```
FOVs:   0%|          | 0/1 [00:00<?, ?it/s]
FOV effects: 0it [00:00, ?it/s]
FOVs: 100%|| 1/1 [00:00<00:00, 14.10it/s]
Image Plane effects: 100%|| 1/1 [00:00<00:00, 5405.03it/s]
```

[15]:
```
<matplotlib.image.AxesImage at 0x7fdcdd654310>
```



Here we can see that there is a certain amount of sub-pixel jitter being introduced into each observation. However this bare-bones approach is not very realistic. We should therefore turn the PSF back on to get a more realistic observation:

[16]:
```
micado["relay_psf"].include = True

micado.observe(src, update=True)
hdus = micado.readout()

plt.figure(figsize=(8,8))
plt.imshow(hdus[0][1].data, origin="lower", norm=LogNorm())
```

```
 FOVs:   0%|          | 0/1 [00:00<?, ?it/s]
```

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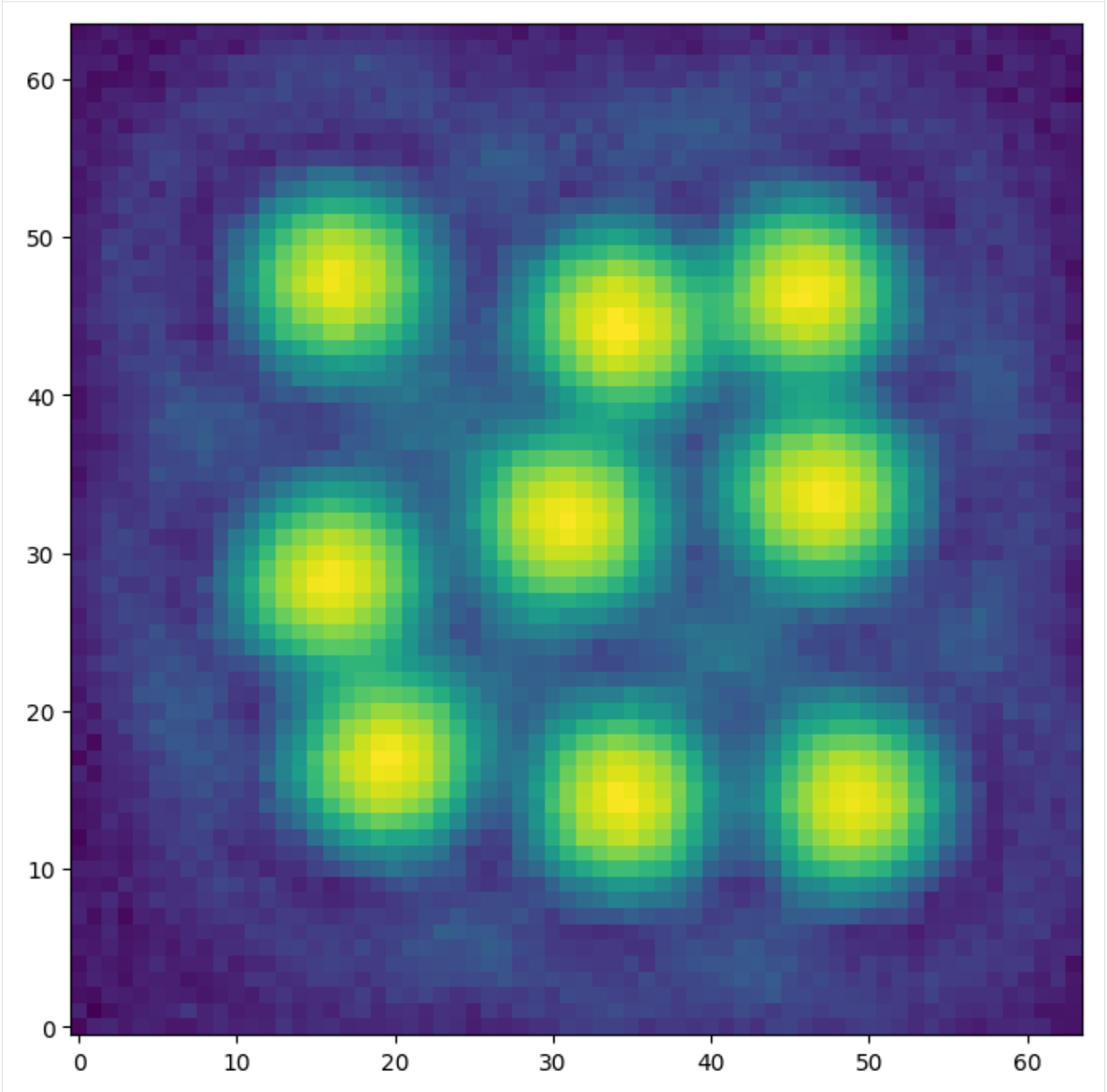
```
 FOV effects:   0%|          | 0/1 [00:00<?, ?it/s]
astar.scopesim.effects.psf_utils - WARNING: PSF center off

 FOVs: 100%|| 1/1 [00:00<00:00, 10.96it/s]
 Image Plane effects: 100%|| 1/1 [00:00<00:00, 5035.18it/s]
astar.scopesim.detector.detector_array - Extracting from 1 detectors...

```

[16]: <matplotlib.image.AxesImage at 0x7fdcdd4d8c90>



[ ]:

CHAPTER

SIX

HINTS AND TRICKS

6.1 Using !-string and #-string commands

6.1.1 !-strings are for setting simulation parameters

!-strings are a convenient way of accessing multiple layers of a nested dictionary structure with a single string using the format:

```
"!<ALIAS>.<sub-dict>...<sub-dict>.<param>"
```

Any level of the nested dictionary can be reached by truncating the keyword.

Note: !-strings only work on ``UserCommands`` objects

Below is an example of how to use !-strings, using the example optical train.

[ ]:
```
import scopesim as sim
opt = sim.load_example_optical_train()
```

[ ]:
```
opt.cmds["!ATMO"]
```

[ ]:
```
opt.cmds["!ATMO.background"]
```

[ ]:
```
opt.cmds["!ATMO.background.filter_name"]
```

6.1.2 #-strings are for accessing Effect object parameters

Similar to !-strings, #-strings allow us to get at the preset values inside the Effect-objects of the optical system. #-strings allow us to pring the contents of an effect's meta dictionary.

Note: !-strings only work on ``OpticalTrain`` objects

Here, we're again using the example optical train defined above. First let's list the effects:

[ ]:
```
opt.effects
```

We list the meta dictionary contents by using the string format

```
"#<effect-name>."
```

Note: The ``.`` at the end is important, otherwise the optical train will look for a non-existant effect named ``#<effect-name>``

[ ]:
```
opt["#exposure_action."]
```

We print a specific meta parameter by adding it after the `.`

[ ]:
```
opt["#exposure_action.ndit"]
```

Notice that the value of this dictionary entry is itself a !-string. We can resolve this by adding a `!` to the end of the string, to force it to get the actual value from `opt.cmds`:

[ ]:
```
opt["#exposure_action.ndit!"]
```

6.2 Turning Effect objects on or off

To list all the effects in an optical train, we do use the `effects` attribute.

Alternatively, we can call `opt.optics_manager.all_effects()`

[ ]:
```
import scopesim as sim

opt = sim.load_example_optical_train()
opt.effects
```

Turning an effect on or off is as simple as using setting the `.include` attribute to `true` or `False`:

[ ]:
```
opt["slit_wheel"].include = True
opt["slit_wheel"].include = False
```

[ ]:
```

```

6.3 Downloading packages

Note: Instrument packages are kept in a separate repository:the Instrument Reference Database (IRDB)

Before simulating anything we need to get the relevant instrument packages. Packages are split into the following categories

- Locations (e.g. Armazones, LaPalma)
- Telescopes (e.g. ELT, GTC)
- Instruments (e.g. MICADO, METIS, MORFEO, OSIRIS, MAAT)

We need to amke sure we have all the packages required to built the optical system. E.g. observing with MICADO is useless without including the ELT.

[ ]:
```
import scopesim as sim

from tempfile import TemporaryDirectory
tmpdir = TemporaryDirectory()
sim.rc.__config__["!SIM.file.local_packages_path"] = tmpdir.name
```

6.3.1 scopesim.download_packages()

Stable packages

The simplest way is to simply get the latest stable versions of the packages by calling their names.

Call `list_packages()` or see the IRDB for names.

[ ]:
```
sim.list_packages()
```

[ ]:
```
sim.download_packages(["Armazones", "ELT", "MICADO"])
```

Development version

Use the `release="latest"` parameter to get the latest stable development verions of the packages

[ ]:
```
sim.download_packages("test_package", release="latest")
```

Bleeding-edge versions from GitHub

We can also pull the latest verisons of a package from GitHub. This is useful if you are the one writing the package and want to test how it works on a different machine.

The following strings will work:

- Latest from a branch: `release="github:<branch-name>"`
- From a specific tag: `release="github:<tag>"`
- From a specific commit: `release="github:<super-long-commit-hash>"`

[ ]:
```
sim.download_packages("test_package", release="github:dev_master")
```

[ ]:
```
sim.download_packages("LFOA", release="github:3c136cd59ceeca551c01c6fa79f87377997f33f9")
```

6.4 Science target templates

The companion python package ScopeSim-Templates contains a library of helper functions for generating ScopeSim-friendly `Source` objects for various common astronomical sources.

For more information, please see the ScopeSim-Templates documentation

[ ]:
```
import numpy as np
import matplotlib.pyplot as plt
from matplotlib.colors import LogNorm

import scopesim_templates as sim_tp
```

6.4.1 A basic star cluster

```
[ ]: my_cluster = sim_tp.stellar.clusters.cluster(mass=1000.0,       # [Msun]
                                                  distance=8000,     # [pc]
                                                  core_radius=1)     # [pc]
     my_cluster.plot()
```

6.4.2 A basic elliptical galaxy

```
[ ]: # See the docstring of `elliptical` for more keywords
     my_elliptical = sim_tp.extragalactic.galaxies.elliptical(half_light_radius=30,   #␣
     ↪[arcsec]
                                                              pixel_scale=0.1,        #␣
     ↪[arcsec]
                                                              filter_name="Ks",
                                                              amplitude=10,
                                                              normalization="total",  #␣
     ↪[Ks=10 for integrated flux]
                                                              n=4,                    #␣
     ↪Sersic index
                                                              ellipticity=0.5,
                                                              angle=30)

     plt.figure(figsize=(12, 5))
     plt.subplot(121)
     plt.imshow(my_elliptical.fields[0].data, norm=LogNorm(), extent=[-25.6, 25.6, -25.6, 25.
     ↪6])
     plt.xlabel("[arcsec]")
     plt.subplot(122)
     wave = np.arange(5000, 25000)   # [angstrom]
     plt.plot(wave, my_elliptical.spectra[0](wave))
     plt.xlabel("Wavelength [Angstrom]")
```

6.5 Global rc simulation parameters

Default global simulation parameters used as a base layer for all instruments.

Also accessible via an empty `scopesim.UserCommands()` or via an empty `scopesim.OpticalTrain()`object

```
[ ]: import scopesim

     scopesim.rc.__currsys__["!SIM.random.seed"] = 9001
     scopesim.rc.__currsys__["!SIM.file.local_packages_path"] = "./"

     scopesim.rc.__currsys__["!SIM"]
```

6.6 Source : from FITS images

We can use a FITS image as the Source object for a ScopeSim Simulation

Warning: The simulation output is only as good as the input

If the pixel scale of the input (`CDELTn`) is bigger than the pixel scale of the instrument, ScopeSim will simply interpolate the image.

Please don't expect wonders if the input image WCS information is not appropriate for the instrument you are using.

ScopeSim Source objects can be generated from fits.ImageHDU object in the following ways:

1. Just an Image and scaling flux value
2. An Image and the associated synphot Spectrum
3. An Image and arrays for wavelength and flux

- `image_hdu=<fits.ImageHDU>` + `flux=<astropy.Quantity>`
- `image_hdu=<fits.ImageHDU>` + `spectra=<list of synphot.SourceSpectrum>`
- `image_hdu=<fits.ImageHDU>` + `lam=<array>` + `spectra=<list of arrays>`

[ ]:
```
import numpy as np
import scipy
import astropy.io.fits as fits
from astropy import units as u
import matplotlib.pyplot as plt
%matplotlib inline

import scopesim

# Make an ImageHDU with some pixel data
hdu = fits.ImageHDU(data=scipy.misc.face(gray=True))

# Give the header some proper WCS info
hdu.header.update({"CDELT1": 1, "CUNIT1": "arcsec", "CRPIX1": 0, "CRVAL1": 0,
                   "CDELT2": 1, "CUNIT2": "arcsec", "CRPIX2": 0, "CRVAL2": 0,})


# plotting function for later
def plot(src):
    plt.figure(figsize=(12, 5))
    plt.subplot(121)
    wave = range(3000, 25000)
    plt.plot(wave, image_source.spectra[0](wave))
    plt.xlabel("Wavelength [Angstrom]")
    plt.ylabel("Flux [ph/s/cm2/Angstrom]")
    plt.subplot(122)
    plt.imshow(image_source.fields[0].data)
```

6.6.1 1. Just an Image and scaling flux value

`image_hdu=<fits.ImageHDU>` + `flux=<astropy.Quantity>`

It is assumed that the flux definied here is **integrated** flux and is the total flux contained in the image.

Note: In future version, header keywords like ``BUNIT`` etc will also be accepted. This functionality is not yet implemented though (April 2022).

```
[ ]: image_source = scopesim.Source(image_hdu=hdu, flux=10*u.ABmag)

plot(image_source)
```

6.6.2 2. An Image and the associated synphot Spectrum

`image_hdu=<fits.ImageHDU>` + `spectra=<list of synphot.SourceSpectrum>`

In this case, the image pixel values are seen as multipiers for the spectrum at a given coordinate.

Note: It is the users responsibility to make sure the total flux of the "cube" (image * spectrum) is scaled appropriately.

```
[ ]: # Alternatively, see the SpeXtra and Pyckles libraries for more spectra
vega_spec = scopesim.source.source_templates.vega_spectrum(mag=20)

image_source = scopesim.Source(image_hdu=hdu, spectra=[vega_spec])

plot(image_source)
```

6.6.3 3. An Image and arrays for wavelength and flux

`image_hdu=<fits.ImageHDU>` + `lam=<array>` + `spectra=<array of arrays>`

```
[ ]: n = 100
wavelengths = np.geomspace(0.3, 2.5, n) * u.um
flux = np.ones(n)

image_source = scopesim.Source(image_hdu=hdu, lam=wavelengths, spectra=np.array([flux]))

plot(image_source)
```

6.7 Source : Point sources from arrays

Collections of point sources can be initialised through either a collection of arrays, or an astropy Table

```
[ ]: import numpy as np
import astropy.table as table
from astropy import units as u

import scopesim
```

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```
# how many stars
n = 200

# random coordinated in a 100 arcsec box
x, y  = 100 * np.random.random(size=(2, n)) - 50

# All stars reference the Vega spectrum
ref = np.zeros(n)
# Each star is given a different weighting, i.e. magnitude
weight = 10**(-0.4*np.linspace(10, 20, n))

# Note: The Pyckles and SpeXtra libraries contain many more stellar and galactic spectra
vega = scopesim.source.source_templates.vega_spectrum(mag=20)
```

6.7.1 astropy.Table

```
[ ]: tbl = table.Table(names=["x", "y", "ref", "weight"],
                       data= [x,    y,   ref,   weight],
                       units=[u.arcsec, u.arcsec, None, None])

     table_source = scopesim.Source(table=tbl, spectra=[vega])

     table_source.plot()
```

6.7.2 From loose arrays

```
[ ]: point_source = scopesim.Source(spectra=[vega], x=x, y=y, ref=ref, weight=weight)

     point_source.plot()
```

CHAPTER

SEVEN

FAQS

7.1 Binding ScopeSim to a local copy of the IRDB

There may be cases where we would like to have a local copy of all the files and instruments available in the Instrument Reference Database (IRDB). In these cases it is helpful to bind out local version of ScopeSim to the IRDB. This is quite easy and involves only two steps:

1. *Make a local copy of the IRDB*
2. *Tell ScopeSim where to find the IRDB*
    - *By using runtime ScopeSIm commands*
    - *By editing the ScopeSim config file*

7.1.1 Make a local copy of the IRDB

First we must clone the current version of the IRDB from GitHub:

```
$ git clone https://github.com/AstarVienna/irdb.git
```

Note: By default this will clone the `master` branch of the IRDB.

To clone a specific branch, either `checkout` the branch you want from `origin` after cloning `master` or specify the branch at clone time with:

```
$ git clone -b dev_master https://github.com/AstarVienna/irdb.git
```

7.1.2 Tell ScopeSim where to find the IRDB

By using runtime ScopeSim commands

At the beginning of any script or jupyter notebook we can run the following command to set the default location of the instrument packages: This is by far the simplest method, but it requires this lone of code in every script:

```
import scopesim
scopesim.rc.__config__["!SIM.file.local_packages_path"] = "<path/to/IRDB>"
```

By editing the ScopeSim config file

Find the `defaults.yaml` file in the top-level of the ScopeSim install directory. This should be here:

```
<path-to-python>/site-packages/scopesim/defaults.yaml
```

Note: Depending on where ScopeSim is installed, we may need administrator permissions to edit this file.

On line 36 (or there abouts), we must replace the default path string (`/inst_pkgs/`) with the path to the top level of our cloned IRDB directory (wherever we chose to put it):

```
file :
  local_packages_path : "./inst_pkgs/"  # --> change this line to point to the top level␣
↪of the local IRDB folder
```

This path can be relative or absolute. If a relative path is used, ScopeSim will look for instrument packages at this location relative to the directory where ScopeSim was executed (e.g. where the notebook session was started).

CHAPTER

EIGHT

EFFECT DESCRIPTIONS

8.1 apertures

8.1.1 ApertureList

A list of apertures, useful for IFU or MOS instruments.

Parameters

Examples

File format

Much like an ApertureMask, an ApertureList can be initialised by either of the three standard DataContainer methods. The easiest is however to make an ASCII file with the following columns:

```
id   left    right   top     bottom  angle  conserve_image  shape
     arcsec  arcsec  arcsec  arcsec  deg
int  float   float   float   float   float  bool            str/int
```

Acceptable `shape` entries are: `round`, `rect`, `hex`, `oct`, or an integer describing the number of corners the polygon should have.

A polygonal mask is generated for a given `shape` and will be scaled to fit inside the edges of each aperture list row. The corners of each aperture defined by shape are found by finding equidistant positions around an ellipse constrained by the edges (`left`, ..., etc). An additional optional column `offset` may be added. This column describes the offset from 0 deg to the angle where the first corner is set.

Additionally, the filename of an `ApertureMask` polygon file can be given. The geometry of the polygon defined in the file will be scaled to fit inside the edges of the row.

Note: `shape` values `"rect"` and `4` do not produce equal results

Both use 4 equidistant points around an ellipse constrained by [`left`, ..., etc]. However `"rect"` aims to fill the contraining area, while `4` simply uses 4 points on the ellipse. Consequently, `4` results in a diamond shaped mask covering only half of the constraining area filled by `"rect"`.

8.1.2 ApertureMask

Only provides the on-sky window coords of the Aperture.

- **Case: Imaging**
  - Covers the whole FOV of the detector
  - Round (with mask), square (without mask)
- **Case**
  [LS Spec]
  - Covers the slit FOV
  - Polygonal (with mask), square (without mask)
- **Case**
  [IFU Spec]
  - Covers the on-sky FOV of one slice of the IFU
  - Square (without mask)
- **Case**
  [MOS Spec]
  - Covers a single MOS fibre FOV
  - Round, Polygonal (with mask), square (without mask)

The geometry of an `ApertureMask` can be initialised with the standard DataContainer methods (see Parameters below). Regardless of which method is used, the following columns must be present:

```
x       y
arcsec  arcsec
float   float
```

Certain keywords need to also be included in the ascii header:

```
# id: <int>
# conserve_image: <bool>
# x_unit: <str>
# y_unit: <str>
```

If `conserve_image` is `False`, the flux from all sources in the aperture is summed and distributed uniformly over the aperture area.

Parameters

filename
[str] Path to ASCII file containing the columns listed above

table
[astropy.Table] An astropy Table containing the columns listed above

array_dict
[dict] A dictionary containing the columns listed above: `{x: [...], y: [...], id: <int>, conserve_image: <bool>}`

Other Parameters

pixel_scale
: [float] [arcsec] Defaults to "`!INST.pixel_scale`" from the config

id
: [int] An integer to identify the `ApertureMask` in a list of apertures

8.1.3 RectangularApertureMask

8.1.4 SlitWheel

Selection of predefined spectroscopic slits and possibly other field masks.

It should contain an open position. A user can define a non-standard slit by directly using the Aperture effect.

Parameters

slit_names : list of str

filename_format
: [str] A f-string for the path to the slit files

current_slit
: [str] Default name

Examples

This Effect assumes a folder full of ASCII files containing the edges of each slit. Each file should be names the same except for the slit's name or identifier.

This example assumes a folder `masks` containing the slit ASCII files with the naming convention: `slit_A.dat`, `slit_B.dat`, etc.

```
name: slit_wheel
class: SlitWheel
kwargs:
    slit_names:
        - A
        - B
        - C
    filename_format: "masks/slit_{}.dat
    current_slit: "C"
```

8.2 detector_list

8.2.1 DetectorList

A description of detector positions and properties.

The list of detectors must have the following table columns

```
id   x_cen   y_cen  x_size  y_size  pixel_size  angle    gain
```

where:

- "id" is a reference id for the chip (fits header EXTNAME)
- "x_cen" and "y_cen" [mm] are the physical coordinates of centre of the chip on the detector plane
- "x_size", "y_size" [mm, pixel] are the width/height of the chip
- "pixel_size" [mm] is the physical size of pixels in the detector
- "angle" [deg] is the rotation of the detector relative to the x-axis
- "gain" [e-/ADU] is the conversion factor for electrons (photons) to ADUs

The units for each column (except `id`) must be given in the meta data using the format `<colname>_unit`. E.g. `x_size_unit`. See examples below.

Note: Currently only the units specified below are accepted.

For `x(y)_size_unit`, acceptable units are `mm`, `pixel`

Parameters

filename
: [str, optional] Filename of the ASCII file with the detector description. See examples

array_dict
: [dict] Dict containing the detector description. See examples

image_plane_id
: [int] Which image plane the detector will look at (generally 0)

Examples

With the `array_dict` feature

```
-   name: single_detector
    class: DetectorList
    kwargs:
        image_plane_id : 0
        array_dict:
            id: [1]
            x_cen: [0.]
            y_cen: [0.]
            x_size: [5.12]
```

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```
            y_size: [5.12]
            pixel_size: [0.01]
            angle: [0.]
            gain: [1.0]
        x_cen_unit: mm
        y_cen_unit: mm
        x_size_unit: mm
        y_size_unit: mm
        pixel_size_unit: mm
        angle_unit: deg
        gain_unit: electron/adu
```

Or referring to a table contained in a seperate ASCII file

```
- name : full_detector_array
  class : DetectorList
  kwargs :
    filename : "detecotr_list.dat"
    active_detectors : [1, 3]
    image_plane_id : 0
```

where the file detector_list.dat contains the following information

```
# x_cen_unit : mm
# y_cen_unit : mm
# x_size_unit : pix
# y_size_unit : pix
# pixel_size_unit : mm
# angle_unit : deg
# gain_unit : electron/adu
#
id   x_cen   y_cen  x_size  y_size  pixel_size  angle    gain
1   -63.94    0.00    4096    4096       0.015    0.0     1.0
2     0.00    0.00    4096    4096       0.015   90.0     1.0
3    63.94    0.00    4096    4096       0.015  180.0     1.0
```

8.2.2 DetectorWindow

For when a full DetectorList if too cumbersome.

Parameters

pixel_size
: [float] [mm pixel-1] Physical pixel size

x, y
: [float] [mm] Position of window centre relative to optical axis

width, height=None
: [float] [mm] Dimensions of window. If height is None, height=width

angle
: [float, optional] [deg] Rotation of window

gain
: [float, optional] [ADU/e-]

units
: [str, optional] [mm, pixel] Default "mm". Sets the input parameter units. If `"pixel"`, (`x`, `y`, `width`, `height`) are multiplied by `pixel_size`

8.3 effects

8.3.1 Effect

Base class for representing the effects (artifacts) in an optical system.

The `Effect` class is conceived to independently apply the changes that an optical component (or series thereof) has on an incoming 3D description of an on-sky object. In other words, **an Effect object should receive a derivative of a ``Source`` object, alter it somehow, and return it**.

The interface for the Effect base-class has been kept very general so that it can easily be sub-classed as data for new effects becomes available. Essentially, a sub-classed Effects object must only contain the following attributes:

- `self.meta` - a dictionary to contain metadata.
- `self.apply_to(obj, **kwargs)` - a method which accepts a Source-derivative and returns an instance of the same class as `obj`
- `self.fov_grid(which="", **kwargs)`

Parameters

See `DataContainer` for input parameters

8.4 electronic

8.4.1 AutoExposure

Determine DIT and NDIT automatically from ImagePlane.

DIT is determined such that the maximum value in the incident photon flux (including astronomical source, sky and thermal backgrounds) fills the full well of the detector (`!DET.full_well`) to a given fraction (`!OBS.autoexposure.fill_frac`). NDIT is determined such that `DIT` * `NDIT` results in the requested exposure time.

The requested exposure time is taken from `!OBS.exptime`.

The effects sets the parameters *!OBS.dit* and *!OBS.ndit*.

Examples

The parameters *!OBS.exptime*, *!DET.full_well* and *!DET.mindit* should be defined as properties in the respective subsections.

```
name: auto_exposure
description: automatic determination of DIT and NDIT
class: AutoExposure
include: True
kwargs:
    fill_frac: "!OBS.auto_exposure.fill_frac"
```

8.4.2 BasicReadoutNoise

Readout noise computed as: ron * sqrt(NDIT).

8.4.3 Bias

Adds a constant bias level to readout.

8.4.4 BinnedImage

8.4.5 DarkCurrent

required: dit, ndit, value

8.4.6 DetectorModePropertiesSetter

Set mode specific curr_sys properties for different detector readout modes.

A little class (`DetectorModePropertiesSetter`) that allows different `"!DET"` properties to be set on the fly.

Parameters

mode_properties
: [dict] A dictionary containing the DET parameters to be changed for each mode. See below for an example yaml entry.

Examples

Add the values for the different detector readout modes to all the relevant detector yaml files. In this case the METIS HAWAII (L, M band) and GeoSnap (N band) detectors: METIS_DET_IMG_LM.yaml , METIS_DET_IMG_N.yaml

```
- name: lm_detector_readout_parameters
  class: DetectorModePropertiesSetter
  kwargs:
    mode_properties:
      fast:
```

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```
        mindit: 0.04
        full_well: !!float 1e5
        ron: 70
      slow:
        mindit: 1.3
        full_well: !!float 1e5
        ron: 14
```

Add the OBS dict entry !OBS.detector_readout_mode to the properties section of the mode_yamls descriptions in the default.yaml files.

```
mode_yamls:
  - object: observation
    alias: OBS
    name: lss_l
    yamls:
      ...
    properties:
      ...
      detector_readout_mode: slow
```

8.4.7 LinearityCurve

Detector linearity effect.

The detector linearity curve is set in terms of *incident* flux (e/s) and *measured* detector values (ADU).

Examples

The effect can be instantiated in various ways.:

```
- name: detector_linearity
  class: LinearityCurve
  kwargs:
    filename: FPA_linearity.dat

- name: detector_linearity
  class: LinearityCurve
  kwargs:
    array_dict: {incident: [0, 77000, 999999999999],
                 measured: [0, 77000, 77000]}

- name: detector_linearity
  class: LinearityCurve
  kwargs:
    incident: [0, 77000, 99999999]
    measured: [0, 77000, 77000]
```

8.4.8 PoorMansHxRGReadoutNoise

8.4.9 Quantization

Converts raw data to whole photons.

8.4.10 ReferencePixelBorder

8.4.11 ShotNoise

8.4.12 SummedExposure

Simulates a summed stack of `ndit` exposures.

8.4.13 UnequalBinnedImage

8.5 fits_headers

8.5.1 EffectsMetaKeywords

Adds meta dictionary info from all Effects to the FITS headers.

Parameters

ext_number
: [int, list of ints, optional] Default 0. The numbers of the extensions to which the header keywords should be added

add_excluded_effects
: [bool, optional] Default False. Add meta dict for effects with `<effect>.include=False`

keyword_prefix
: [str, optional] Default "HIERARCH SIM". Custom FITS header keyword prefix. Effect meta dict entries will appear in the header as: `<keyword_prefix> EFFn <key> : <value>`

Examples

Yaml file entry:

```
name: effect_dumper
class: EffectsMetaKeywords
description: adds all effects meta dict entries to the FITS header
kwargs:
  ext_number: [0, 1]
  add_excluded_effects: False
  keyword_prefix: HIERARCH SIM
```

8.5.2 ExtraFitsKeywords

Extra FITS header keywords to be added to the pipeline FITS files.

These keywords are ONLY for keywords that should be MANUALLY ADDED to the headers after a simulation is read-out by the detector.

Simulation parameters (Effect kwargs values, etc) will be added automatically by ScopeSim in a different function, but following this format.

The dictionaries should be split into different HIERARCH lists, e.g.:

- HIERARCH ESO For ESO specific keywords
- HIERARCH SIM For ScopeSim specific keywords, like simulation parameters
- HIERARCH MIC For MICADO specific keywords, (unsure what these would be yet)

More HIERARCH style keywords can also be added as needed for other use-cases.

Parameters

filename
: [str, optional] Name of a .yaml nested dictionary file. See below for examples

yaml_string
: [str, optional] A triple-" string containing the contents of a yaml file

header_dict
: [nested dicts, optional] A series of nested python dictionaries following the format of the examples below. This keyword allows these dicts to be definied directly in the Effect yaml file, rather than in a seperate header keywords file.

Examples

Specifying the extra FITS keywords directly in the .yaml file where the Effect objects are described.

```
name: extra_fits_header_entries
class: ExtraFitsKeywords
kwargs:
  header_dict:
    - ext_type: PrimaryHDU
      keywords:
        HIERARCH:
          ESO:
            ATM:
              TEMPERAT: -5
```

The contents of `header_dict` can also be abstracted away into a seperate file, e.g. `extra_FITS_keys.yaml`. The file format is described below in detail below.

```
name: extra_fits_header_entries
class: ExtraFitsKeywords
kwargs:
  filename: extra_FITS_keys.yaml
```

The Effect can be added directly in an iPython session.

```
>>> hdr_dic = {"ext_type": "PrimaryHDU",
               "keywords":
                   {"HIERARCH":
                       {"SIM":
                           {"hello": world}
                       }
                   }
               }
>>> extra_keys = ExtraFitsKeywords(header_dict=hdr_dic)
>>> optical_train.optics_manager.add_effect(extra_keys)
```

Yaml file format

This document is a yaml document. Hence all new keywords should be specified in the form of yaml nested dictionaries. As each `astropy.HDUList` contains one or more extensions, the inital level is reserved for a list of keyword groups. For example:

```
- ext_type: PrimaryHDU
  keywords:
    HIERARCH:
      ESO:
        ATM:
          TEMPERAT: -5

- ext_number: [1, 2]
  keywords:
    HIERARCH:
      ESO:
        DET:
          DIT: [5, '[s] exposure length']   # example of adding a comment
    EXTNAME: "DET§.DATA"                   # example of extension specific qualifier
```

The keywords can be added to one or more extensions, based on one of the following `ext_` qualifiers: `ext_name`, `ext_number`, `ext_type`

Each of these `ext_` qualifiers can be a `str` or a `list`. For a list, ScopeSim will add the keywords to all extensions matching the specified type/name/number

The number of the extension can be used in a value by using the "§" string. That is, keyword values with "§" with have the extension number inserted where the "§" is.

The above example (`EXTNAME: "DET§.DATA"`) will result in the following keyword added only to extensions 1 and 2:

- PrimaryHDU (ext 0):

  ```
  header['HIERARCH ESO ATM TEMPERAT'] = -5
  ```

- Extension 1 (regardless of type):

  ```
  header['HIERARCH ESO DET DIT'] = (5, '[s] exposure length')
  header['EXTNAME'] = "DET1.DATA"
  ```

- Extension 2 (regardless of type):

```
header['HIERARCH ESO DET DIT'] = (5, '[s] exposure length')
header['EXTNAME'] = "DET2.DATA"
```

Resolved and un-resolved keywords

ScopeSim uses bang-strings to resolve global parameters. E.g: `from_currsys('!ATMO.temperature')` will resolve to a float These bang-strings will be resolved automatically in the `keywords` dictionary section.

If the keywords bang-string should instead remain unresolved and the string added verbatim to the header, we use the `unresolved_keywords` dictionary section.

Additionally, new functionality will be added to ScopeSim to resolve the kwargs/meta parameters of Effect objects. The format for this will be to use a new type: the hash-string. This will have this format:

```
#<optical_element_name>.<effect_name>.<kwarg_name>
```

For example, the temperature of the MICADO detector array can be accessed by:

```
'#MICADO_DET.full_detector_array.temperature'
```

In the context of the yaml file this would look like:

```
- ext_type: PrimaryHDU
  keywords:
    HIERARCH:
      ESO:
        DET
          TEMPERAT: '#MICADO_DET.full_detector_array.temperature'
```

Obviously some though needs to be put into how exactly we list the simulation parameters in a coherent manner. But this is 'Zukunftsmusik'. For now we really just want an interface that can add the ESO header keywords, which can also be expanded in the future for our own purposes.

Below is an example of some extra keywords for MICADO headers:

```
- ext_type: PrimaryHDU
  keywords:
    HIERARCH:
      ESO:
        ATM:
          TEMPERAT: '!ATMO.temperature'   # will be resolved via from_currsys
          PWV: '!ATMO.pwv'
          SEEING: 1.2
        DAR:
          VALUE: '#<effect_name>.<meta_name>'   # will be resolved via effects
        DPR:
          TYPE: 'some_type'
      SIM:
        random_simulation_keyword: some_value
      MIC:
        micado_specific: ['keyword', 'keyword comment']

  unresolved_keywords:
    HIERARCH:
```

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```
      ESO:
        ATM:
          TEMPERAT: '!ATMO.temperature'   # will be left as a string

- ext_type: ImageHDU
  keywords:
    HIERARCH:
      SIM:
        hello: world
        hallo: welt
        grias_di: woed
        zdrasviute: mir
        salud: el mundo
```

8.5.3 SimulationConfigFitsKeywords

Adds parameters from all config dictionaries to the FITS headers.

Parameters

ext_number
: [int, list of ints, optional] Default 0. The numbers of the extensions to which the header keywords should be added

resolve
: [bool] Default True. If True, all !-strings and #-strings are resolved via `from_currsys` before being add to the header. If False, the unaltered !-strings or #-strings are added to the header.

keyword_prefix
: [str, optional] Default "HIERARCH SIM". Custom FITS header keyword prefix. Effect meta dict entries will appear in the header as: `<keyword_prefix> SRCn <key> : <value>`

Examples

Yaml file entry:

```
name: source_descriptor
class: SimulationConfigFitsKeywords
description: adds info from all config dicts to the FITS header
kwargs:
  ext_number: [0]
  resolve: False
  keyword_prefix: HIERARCH SIM
```

8.5.4 SourceDescriptionFitsKeywords

Adds parameters from all Source fields to the FITS headers.

Parameters

ext_number
: [int, list of ints, optional] Default 0. The numbers of the extensions to which the header keywords should be added

keyword_prefix
: [str, optional] Default "HIERARCH SIM". Custom FITS header keyword prefix. Effect meta dict entries will appear in the header as: `<keyword_prefix> SRCn <key> : <value>`

Examples

Yaml file entry:

```
name: source_descriptor
class: SourceDescriptionFitsKeywords
description: adds info from all Source fields to the FITS header
kwargs:
  ext_number: [0]
  keyword_prefix: HIERARCH SIM
```

8.6 metis_lms_trace_list

8.6.1 MetisLMSEfficiency

Computes the grating efficiency (blaze function) for the METIS LMS.

The procedure is described in E-REP-ATC-MET-1016_1.0. For a given order (determined by the central wavelength) the grating efficiency is modelled as a squared sinc function of wavelength via the grating angle.

8.6.2 MetisLMSImageSlicer

Treats the METIS LMS image slicer as an aperture mask effect.

This helps in building a `FieldOfView` object that combines the spatial field of the slicer with the spectral range covered by the LMS setting.

The effect differs from its parent class `ApertureMask` in the initialisation from the *Aperture List* extension of the trace file *!OBS.trace_file*.

8.6.3 MetisLMSSpectralTraceList

SpectralTraceList for the METIS LM spectrograph.

8.7 obs_strategies

8.7.1 ChopNodCombiner

Creates and combines 4 images for each of the chop/nod positions.

- AA : original position `(dx, dy) = (0, 0)`
- AB : chop position `(dx, dy) = chop_offsets`
- BA : nod position `(dx, dy) = nod_offsets`
- BB : chop-nod position `(dx, dy) = nod_offsets + chop_offsets`

Images are combined using:

```
im_combined = (AA - AB) - (BA - BB)
```

If no `nod_offset` is given, it is set to the inverse of `chop_offset`.

`ChopNodCombiner` is a detector effect and should be placed last in the
detector yaml (after the noise effects).

Keyword Arguments

chop_offsets
[tuple, optional] [arcsec] (dx, dy) offset of chop position relative to AA

nod_offsets
[tuple, optional] [arcsec] (dx, dy) offset of nod position relative to AA

Example yaml entry

```
name: perpendicular_chop_nod_slanted_pattern
description: chop throw to (+5, 0) and nod throw to (-7, +10) arcsec
class: ChopNodCombiner
include: True
kwargs:
    pixel_scale : "!INST.pixel_scale"
    chop_offsets : (5, 0)
    nod_offsets : (-7, 10)
```

8.8 psfs

8.8.1 AnalyticalPSF

8.8.2 AnisocadoConstPSF

Makes a SCAO on-axis PSF with a desired Strehl ratio at a given wavelength.

To make the PSFs a map connecting Strehl, Wavelength, and residual wavefront error is required.

Parameters

filename
: [str] Path to Strehl map with axes (x, y) = (wavelength, wavefront error).

strehl
: [float] Desired Strehl ratio. Either percentage [1, 100] or fractional [1e-3, 1].

wavelength
: [float] [um] The given strehl is valid for this wavelength.

psf_side_length
: [int] [pixel] Default is 512. Side length of the kernel images.

offset
: [tuple] [arcsec] SCAO guide star offset from centre (dx, dy).

rounded_edges
: [bool] Default is True. Sets all halo values below a threshold to zero. The threshold is determined from the max values of the edge rows of the kernel image.

Other Parameters

convolve_mode
: [str] [“same”, “full”] convolution keywords from scipy.signal.convolve

Examples

Add an AnisocadoConstPSF with code:

```
from scopesim.effects import AnisocadoConstPSF
psf = AnisocadoConstPSF(filename="test_AnisoCADO_rms_map.fits",
                        strehl=0.5,
                        wavelength=2.15,
                        convolve_mode="same",
                        psf_side_length=512)
```

Add an AnisocadoConstPSF to a yaml file:

```
effects:
-   name: Ks_Stehl_40_PSF
    description: A 40% Strehl PSF over the field of view
    class: AnisocadoConstPSF
```

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```
    kwargs:
        filename: "test_AnisoCADO_rms_map.fits"
        strehl: 0.5
        wavelength: 2.15
        convolve_mode: full
        psf_side_length: 512
```

8.8.3 DiscretePSF

8.8.4 FieldConstantPSF

A PSF that is constant across the field.

For spectroscopy, a wavelength-dependent PSF cube is built, where for each wavelength the reference PSF is scaled proportional to wavelength.

8.8.5 FieldVaryingPSF

TBA.

Parameters

sub_pixel_flag : bool, optional flux_accuracy : float, optional

Default 1e-3. Level of flux conservation during rescaling of kernel

8.8.6 GaussianDiffractionPSF

8.8.7 NonCommonPathAberration

TBA.

Needed: pixel_scale Accepted: kernel_width, strehl_drift

8.8.8 PSF

8.8.9 SeeingPSF

Currently only returns gaussian kernel with a `fwhm` [arcsec].

Parameters

fwhm
[flaot] [arcsec]

8.8.10 SemiAnalyticalPSF

8.8.11 Vibration

Creates a wavelength independent kernel image.

8.9 rotation

8.9.1 Rotate90CCD

Rotates CCD by integer multiples of 90 degrees.

rotations kwarg is number of counter-clockwise rotations

Author: Dave jones

8.10 shifts

8.10.1 AtmosphericDispersion

Used to generate the wavelength bins based on shifts due to the atmosphere.

Doesn't contain an `apply_to` function, but provides information through the `fov_grid` function.

Required Parameters

airmass
[float] Recommended to use "!OBS.airmass" in the OBS properties

temperature
[float] [degC] Recommended to use "!ATMO.temperature" in the ATMO properties

humidity
[float] [0..1] Recommended to use "!ATMO.humidity" in the ATMO properties

pressure
[float] [bar] Recommended to use "!ATMO.pressure" in the ATMO properties

latitude
[float] [deg] Recommended to use "!ATMO.latitude" in the ATMO properties

altitude
[m] Recommended to use "!ATMO.altitude" in the ATMO properties

pixel_scale
[arcsec] Recommended to use "!INST.pixel_scale" in the INST properties

Optional Parameters

wave_min
[float] [um] Defaults to "!SIM.spectral.wave_min"

wave_mid
[float] [um] Defaults to "!SIM.spectral.wave_mid"

wave_max
[float] [um] Defaults to "!SIM.spectral.wave_max"

sub_pixel_fraction
[float] [0..1] Defaults to "!SIM.sub_pixel.fraction"

num_steps
[int] Default: 1000. Number of wavelength steps to use when interpolating the atmospheric dispersion curve

8.10.2 AtmosphericDispersionCorrection

Alters the position on the detector for a FOV object (WCS_prefix="D").

Only acts on FOVs during the main effects loop in OpticalTrain. For the sake of computational efficiency, the ADC can be instructed to counteract the atmospheric diffraction during the OpticalTrain setup phase, by passing the kwarg: `quick_adc=True`

Parameters

kwargs

8.10.3 Shift3D

8.11 shutter

8.11.1 Shutter

Simulate a closed shutter, useful for dark exposures.

8.12 spectral_efficiency

8.12.1 SpectralEfficiency

Applies the grating efficiency (blaze function) for a SpectralTraceList.

Input Data Format

The efficiency curves are taken from a fits file *filename `with a structure similar to the trace definition file (see `SpectralTraceList*). The required extensions are: - 0 : PrimaryHDU [header] - 1 : BinTableHDU or TableHDU[header, data] : Overview table of all traces - 2..N : BinTableHDU or TableHDU : Efficiency curves, one per trace. The

tables must have the two columns *wavelength* and *efficiency*

Note that there must be one extension for each trace defined in the *SpectralTraceList*. Extensions for other traces are ignored.

8.12.2 EXT 0 : PrimaryHDU

Required header keywords:

- ECAT : int : Extension number of overview table, normally 1
- EDATA : int : Extension number of first Trace table, normally 2

No data is required in this extension

8.12.3 EXT 1 : (Bin)TableHDU : Overview of traces

No special header keywords are required in this extension.

Required Table columns: - description : str : identifier for each trace - extension_id : int : which extension is each trace in

8.12.4 EXT 2 : (Bin)TableHDU : Efficiencies for individual traces

Required header keywords: - EXTNAME : must be identical to the *description* in EXT 1

Required Table columns: - wavelength : float : [um] - efficiency : float : number [0..1]

8.13 spectral_trace_list

8.13.1 SpectralTraceList

List of spectral trace geometries for the detector plane.

Should work in concert with an ApertureList (or ApertureMask) object and a DetectorList object

Spectral trace patterns are to be kept in a `fits.HDUList` with one or more `fits.BinTableHDU` extensions, each one describing the geometry of a single trace. The first extension should be a `BinTableHDU` connecting the traces to the correct `Aperture` and `ImagePlane` objects.

The `fits.HDUList` objects can be loaded using one of these two keywords:

- `filename`: for on disk FITS files, or
- `hdulist`: for in-memory `fits.HDUList` objects

The format and contents of the extensions in the HDUList (FITS file) object is listed below

Input Data Format

A trace list FITS file needs the following extensions:

- 0 : PrimaryHDU [header]
- 1 : BinTableHDU [header, data] : Overview table of all traces
- 2..N : BinTableHDU [header, data] : Trace tables. One per spectral trace

8.13.2 EXT 0 : PrimaryHDU

Required Header Keywords:

- ECAT : int : Extension number of overview table. Normally 1
- EDATA : int : Extension number of first Trace table. Normally 2

No data is required in this extension

8.13.3 EXT 1 : BinTableHDU : Overview of traces

No special header keywords are required in this extension

Required Table columns:

- description : str : identifier of each trace
- extension_id : int : which extension is each trace in
- aperture_id : int : which aperture matches this trace (e.g. MOS / IFU)
- image_plane_id : int : on which image plane is this trace projected

8.13.4 EXT 2 : BinTableHDU : Individual traces

Required header keywords: - EXTNAME : must be identical to the *description* in EXT 1

Recommended header keywords: - DISPDIR : “x” or “y” : dispersion axis. If not present, Scopesim tries

to determine this automatically; this may be unreliable in some cases.

Required Table columns: - wavelength : float : [um] : wavelength of monochromatic aperture image - s : float : [arcsec] : position along aperture perpendicular to trace - x : float : [mm] : x position of aperture image on focal plane - y : float : [mm] : y position of aperture image on focal plane

8.13.5 SpectralTraceListWheel

A Wheel-Effect object for selecting between multiple gratings/grisms.

See `SpectralTraceList` for the trace file format description.

Parameters

trace_list_names
: [list] The list of unique identifiers in the trace filenames

filename_format
: [str] `f-string` that directs scopesim to the folder containing the trace files. This can be a `!-string` if the trace names are shared with other `*Wheel` effect objects (e.g. a `FilterWheel`). See examples.

current_trace_list
: [str] default trace file to use

kwargs
: [key-value pairs] Addition keywords that are passed to the `SpectralTraceList` objects See SpectralTraceList docstring

Examples

A simplified YAML file example taken from the OSIRIS instrument package:

```
alias: INST
name: OSIRIS_LSS

properties:
  decouple_detector_from_sky_headers: True
  grism_names:
    - R300B
    - R500B
    - R1000B
    - R2500V

effects:
  - name: spectral_trace_wheel
    description: grism wheel contining spectral trace geometries
    class: SpectralTraceListWheel
    kwargs:
      current_trace_list: "!OBS.grating_name"
      filename_format: "traces/LSS_{}_TRACE.fits"
      trace_list_names: "!INST.grism_names"

  - name: grating_efficiency
    description: OSIRIS grating efficiency curves, piggybacking on FilterWheel
    class: FilterWheel
    kwargs:
      minimum_throughput: !!float 0.
      filename_format: "gratings/{}.txt"
      current_filter: "!OBS.grating_name"
      filter_names: "!INST.grism_names"
```

8.14 surface_list

8.14.1 SurfaceList

8.15 ter_curves

8.15.1 ADCWheel

Wheel holding a selection of predefined atmospheric dispersion correctors.

Example

```
name : adc_wheel
class: ADCWheel
kwargs:
    adc_names: []
    filename_format: "TER_ADC_{}.dat"
    current_adc: "const_90"
```

8.15.2 AtmosphericTERCurve

8.15.3 DownloadableFilterCurve

8.15.4 FilterCurve

Descripton TBA.

Parameters

position : int, optional filter_name : str, optional

`Ks` - corresponding to the filter name in the filename pattern

filename_format
[str, optional] `TC_filter_{}.dat`

Can either be created using the standard 3 options: - `filename`: direct filename of the filter curve - `table`: an `astropy.Table` - `array_dict`: a dictionary version of a table: `{col_name1: values, }`

or by passing the combination of `filter_name` and `filename_format` as kwargs. Here all filter file names follow a pattern (e.g. see above) and the `{}` are replaced by `filter_name` at run time. `filter_name` can also be a !bang string for a `__currsys__` entry: `"!INST.filter_name"`

8.15.5 FilterWheel

Wheel holding a selection of predefined filters.

Examples

```
name: filter_wheel
class: FilterWheel
kwargs:
    filter_names: []
    filename_format: "filters/{}.
    current_filter: "Ks"
```

8.15.6 FilterWheelBase

Base class for Filter Wheels.

8.15.7 PupilTransmission

Wavelength-independent transmission curve.

Use this class to describe a cold stop or pupil mask that is characterised by "grey" transmissivity. The emissivity is set to zero, assuming that the mask is cold.

8.15.8 QuantumEfficiencyCurve

8.15.9 SkycalcTERCurve

Retrieve an atmospheric spectrum from ESO's skycalc server.

kwarg parameters

skycalc parameters can be found by calling:

```
>>> import skycalc_ipy
>>> skycalc_ipy.SkyCalc().keys
```

Note: Different to `skycalc_ipy`, *wmin* and *wmax* must be given in units of `um`

Examples

```
- name : skycalc_background
  class : SkycalcTERCurve
  kwargs :
    wunit : "!SIM.spectral.wave_unit"
    wmin : "!SIM.spectral.wave_min"
    wmax : "!SIM.spectral.wave_max"
    wdelta : 0.0001     # 0.1nm bin width
    outer : 1
    outer_unit : "m"
```

8.15.10 SpanishVOFilterCurve

Pulls a filter transmission curve down from the Spanish VO filter service.

Parameters

observatory : str instrument : str filter_name : str

Examples

```
name: HAWKI-Ks
class: SpanishVOFilterCurve
kwargs:
    observatory : Paranal
    instrument : HAWKI
    filter_name : Ks
```

8.15.11 SpanishVOFilterWheel

A FilterWheel that loads all the filters from the Spanish VO service.

> **Warning:** This use `astropy.download_file(..., cache=True)`.

The filter transmission curves probably won't change, but if you notice discrepancies, try clearing the astropy cache:

```
>> from astropy.utils.data import clear_download_cache
>> clear_download_cache()
```

Parameters

observatory : str

instrument : str

current_filter
: [str] Default filter name

include_str, exclude_str
: [str] String sequences that can be used to include or exclude filter names which contain a certain string. E.g. GTC/OSIRIS has curves for `sdss_g` and `sdss_g_filter`. We can force the inclusion of only the filter curves by setting `list_include_str: "_filter"`.

Examples

```
name: svo_filter_wheel
class: SpanishVOFilterWheel
kwargs:
    observatory: "GTC"
    instrument: "OSIRIS"
    current_filter: "sdss_r_filter"
    include_str: "_filter"
```

8.15.12 TERCurve

Transmission, Emissivity, Reflection Curve.

note:: This is basically an `Effect` wrapper for the
: `SpectralSurface` object

Must contain a wavelength column, and one or more of the following: `transmission`, `emissivity`, `reflection`. Additionally, in the header there should be the following keywords: wavelength_unit

kwargs that can be passed:

```
"rescale_emission" : { "filter_name": str, "value": float, "unit": str}
```

Examples

Directly inside a YAML file description:

```
name: bogus_surface
class: TERCurve
kwargs:
    array_dict:
        wavelength: [0.3, 3.0]
        transmission: [0.9, 0.9]
        emission: [1, 1]
    wavelength_unit: um
    emission_unit: ph s-1 m-2 um-1
    rescale_emission:
        filter_name: "Paranal/HAWK.Ks"
```

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```
        value: 15.5
        unit: ABmag
```

Indirectly inside a YAML file:

```
name: some_curve
class TERCurve
kwargs:
    filename: bogus_surface.dat
```

which references this ASCII file:

```
# name: bogus_surface
# wavelength_unit: um
wavelength  transmission    emissivity
0.3         0.9             0.1
3.0         0.9             0.1
```

8.15.13 TopHatFilterCurve

A simple Top-Hat filter profile.

Parameters

transmission
: [float] [0..1] Peak transmission of filter

blue_cutoff, red_cutoff
: [float] [um] Blue and Red cutoff wavelengths

wing_transmission
: [float, optional] [0..1] Default 0. Wing transmission of filter outside the cutoff range

Examples

```
name: J_band_tophat
class: TopHatFilterCurve
kwargs:
    transmission : 0.9
    wing_transmission : 0.001
    blue_cutoff : 1.15
    red_cutoff : 1.35
```

8.15.14 TopHatFilterWheel

A selection of top-hat filter curves as defined in the input lists.

Parameters

filter_names: list of string

transmissions: list of floats
[0..1] Peak transmissions inside the cutoff limits

wing_transmissions: list of floats
[0..1] Wing transmissions outside the cutoff limits

blue_cutoffs: list of floats
[um]

red_cutoffs: list of floats
[um]

current_filter: str, optional
Name of current filter at initialisation. If no name is given, the first entry in *filter_names* is used by default.

Examples

```
name: top_hat_filter_wheel
class: TopHatFilterWheel
kwargs:
    filter_names: ["J", "H", "K"]
    transmissions: [0.9, 0.95, 0.85]
    wing_transmissions: [0., 0., 0.001]
    blue_cutoffs: [1.15, 1.45, 1.9]
    red_cutoffs: [1.35, 1.8, 2.4]
    current_filter: "K"
```

CHAPTER

NINE

SCOPESIM

9.1 scopesim package

9.1.1 Subpackages

scopesim.commands package

Submodules

scopesim.commands.user_commands module

Contains the UserCommands class and some helper functions.

class scopesim.commands.user_commands.**UserCommands**(**maps*, ***kwargs*)

Bases: NestedChainMap

Contains all the setting a user may wish to alter for an optical train.

Most of the important settings are kept in the internal nested dictionary. Setting can be accessed by using the alias names. Currently these are:

- ATMO: atmospheric and observatory location settings
- TEL: telescope related settings
- RO: relay optics settings, i.e. between telescope and instrument
- INST: instrument optics settings
- DET: detector settings
- OBS: observation settings, and
- SIM: simulation settings

All of the settings are contained in a special SystemDict dictionary that allows the user to access all the settings via a bang-string (!). E.g:

```
cmds = UserCommands()
cmds["!SIM.file.local_packages_path]
```

Note: To use this format for accessing hierarchically-stored values, the bang string must always begin with a "!"

Alternatively the same value can be accessed via the normal dictionary format. E.g:

```
cmds["SIM"]["file"]["local_packages_path"]
```

Parameters

use_instrument
[str, optional] The name of the main instrument to use

packages
[list, optional] list of package names needed for the optical system, so that ScopeSim can find the relevant files. E.g. ["Armazones", "ELT", "MICADO"]

yamls
[list, optional] list of yaml filenames that are needed for the combined optical system E.g. ["MICADO_Standalone_RO.yaml", "MICADO_H4RG.yaml", "**MICADO**_.yaml"]

mode_yamls
[list of yamls, optional] list of yaml docs ("OBS" docs) that are applicable only to specific operational modes of the instrument. Further yaml files can be specified in the recursive doc entry: "yamls"

set_modes
[list of strings, optional] A list of default mode yamls to load. E.g. ["SCAO", "IMG_4mas"]

properties
[dict, optional] Any extra "OBS" properties that should be added

ignore_effects
[list] Not yet implemented

add_effects
[list] Not yet implemented

override_effect_values
[dict] Not yet implemented

Notes

Attention: We track your IP address when `ScopeSim` checks for updates

When initialising a UserCommands object via `use_instrument=`, `ScopeSim` checks on the database whether there are updates to the instrument package. Our server records the IP address of each query for out own statistics only.

WE DO NOT STORE OR TRACK PERSONAL DATA. THESE STATISTICS ARE NEEDED FOR GETTING MORE FUNDING TO CONTINUE DEVELOPING THIS PROJECT.

We are doing this solely as a way of showing the austrian funding agency that people are indeed using this software (or not). Your participation in this effort greatly helps our chances of securing the next grant.

However, if you would still like to avoid your IP address being stored, you can run `scopesim` 100% anonymously by setting:

```
>>> scopsim.rc.__config__["!SIM.reports.ip_tracking"] = True
```

at the beginning of each session. Alternatively you can also pass the same bang keyword when generating a `UserCommand` object:

```
>>> from scopesim import UserCommands
>>> UserCommands(use_instrument="MICADO",
```

... properties={"!SIM.reports.ip_tracking": False})

If you use a custom `yaml` configuration file, you can also add this keyword to the `properties` section of the `yaml` file.

Changed in version v0.8.0.

This now inherits from (a subclass of) *collections.ChainMap*.

Examples

Here we use a combination of the main parameters: `packages`, `yamls`, and `properties`. When not using the `use_instrument` key, `packages` and `yamls` must be specified, otherwise scopesim will not know where to look for yaml files (only relevant if reading in yaml files):

```
>>> from scopesim.server.database import download_package
>>> from scopesim.commands import UserCommands
>>>
>>> download_package("test_package")
>>> cmd = UserCommands(packages=["test_package"],
```

... yamls=["test_telescope.yaml", ... {"alias": "ATMO", ... "properties": {"pwv": 9001}}], ... properties={"!ATMO.pwv": 8999})

Attributes

cmds
[RecursiveNestedMapping] Built from the `properties` dictionary of a yaml dictionary. All values here are accessible globally by all `Effects` objects in an `OpticalTrain` once the `UserCommands` has been passed to the `OpticalTrain`.

yaml_dicts
[list of dicts] Where all the effects dictionaries are stored

list_modes() → Iterable[tuple[str, ...]]

Yield tuples of length >= 2 with mode names and descriptions.

Changed in version v0.8.0.

This used to return the formatted string. For a broader range of use cases, it now returns a generator of tuples of strings.

property modes: None

Print all modes, if any.

set_modes(**modes*) → None

Reload with the specified *modes*.

Changed in version v0.8.0.

This used to take a single list-like argument, now used a "*args" approach to deal with multiple modes.

update(*other=None*, */*, ***kwargs*)

Update the current parameters with a yaml dictionary.

See the `UserCommands` main docstring for acceptable kwargs

static update_alias(*mapping: MutableMapping*, *new_dict: Mapping*) → None

Update a dict-like according to the alias-properties syntax.

This used to be part of *astar_utils.NestedMapping*, but is specific to ScopeSim and thus belongs somewhere here. It should only be used in the context of YAML-dicts loaded by UserCommands, hence it was put here.

Module contents

scopesim.detector package

Submodules

scopesim.detector.detector module

class scopesim.detector.detector.**Detector**(*header*, *cmds=None*, ***kwargs*)

Bases: *DetectorBase*

property data

extract_from(*image_plane*, *spline_order=1*, *reset=True*)

property hdu

property header

property image

reset()

scopesim.detector.detector_array module

Contains DetectorArray and aux functions.

class scopesim.detector.detector_array.**DetectorArray**(*detector_list=None*, *cmds=None*, ***kwargs*)

Bases: `object`

Manages the individual Detectors, mostly used for readout.

readout(*image_planes*, *array_effects=None*, *dtcr_effects=None*, ***kwargs*) → HDUList

Read out the detector array into a FITS HDU List.

1. Select the relevant image plane to extract images from.
2. Apply detector array effects (apply to the entire image plane)
3. Make a series of Detectors for each row in a DetectorList object.
4. Iterate through all Detectors, extract image from image_plane.
5. Apply all effects (to all Detectors).
6. Add necessary header keywords (not implemented).

7. Generate a HDUList with the ImageHDUs and any extras:

- add `PrimaryHDU` with meta data regarding observation in header
- add `ImageHDU` objects
- add `ASCIITableHDU` with Effects meta data in final table extension (not implemented)

Parameters

image_planes
[list of ImagePlane objects] The correct image plane is automatically chosen from the list

array_effects
[list of Effect objects] A list of effects related to the detector array

dtcr_effects
[list of Effect objects] A list of effects related to the detectors

Returns

latest_exposure
[fits.HDUList] Output FITS HDU List.

`scopesim.detector.detector_array.`**`make_effects_hdu`**`(`*effects*`)`

`scopesim.detector.detector_array.`**`make_primary_hdu`**`(`*meta*`)`

Create the primary header from meta data.

scopesim.detector.nghxrg module

NGHXRG by Bernard Rauscher see the paper: http://arxiv.org/abs/1509.06264 downloaded from: http://jwst.nasa.gov/publications.html

Module contents

scopesim.effects package

Submodules

scopesim.effects.apertures module

Effects related to field masks, including spectroscopic slits.

`class` `scopesim.effects.apertures.`**`ApertureList`**`(`***kwargs*`)`

Bases: *`Effect`*

A list of apertures, useful for IFU or MOS instruments.

Parameters

`property apertures`

apply_to(*obj*, ***kwargs*)
See parent docstring.

get_apertures(*row_ids*)

plot()

plot_masks()

class scopesim.effects.apertures.**ApertureMask**(***kwargs*)
Bases: *Effect*

Only provides the on-sky window coords of the Aperture.

- **Case: Imaging**
  - Covers the whole FOV of the detector
  - Round (with mask), square (without mask)
- **Case**
  [LS Spec]
  - Covers the slit FOV
  - Polygonal (with mask), square (without mask)
- **Case**
  [IFU Spec]
  - Covers the on-sky FOV of one slice of the IFU
  - Square (without mask)
- **Case**
  [MOS Spec]
  - Covers a single MOS fibre FOV
  - Round, Polygonal (with mask), square (without mask)

The geometry of an `ApertureMask` can be initialised with the standard DataContainer methods (see Parameters below). Regardless of which method is used, the following columns must be present:

```
x       y
arcsec  arcsec
float   float
```

Certain keywords need to also be included in the ascii header:

```
# id: <int>
# conserve_image: <bool>
# x_unit: <str>
# y_unit: <str>
```

If `conserve_image` is `False`, the flux from all sources in the aperture is summed and distributed uniformly over the aperture area.

Parameters

filename
[str] Path to ASCII file containing the columns listed above

table
[astropy.Table] An astropy Table containing the columns listed above

array_dict
[dict] A dictionary containing the columns listed above: `{x: [...], y: [...], id: <int>, conserve_image: <bool>}`

Other Parameters

pixel_scale
[float] [arcsec] Defaults to "`!INST.pixel_scale`" from the config

id
[int] An integer to identify the `ApertureMask` in a list of apertures

apply_to(*obj*, ***kwargs*)

See parent docstring.

fov_grid(*which='edges'*, ***kwargs*)

Return a header with the sky coordinates.

get_header()

get_mask()

For placing over FOVs if the Aperture is rotated w.r.t. the field.

property hdu

property header

property mask

plot(*axes=None*)

required_keys = {'array_dict', 'filename', 'table'}

class scopesim.effects.apertures.**RectangularApertureMask**(***kwargs*)

Bases: *ApertureMask*

get_table(***kwargs*)

required_keys = {'height', 'width', 'x', 'y'}

class scopesim.effects.apertures.**SlitWheel**(***kwargs*)

Bases: *Effect*

Selection of predefined spectroscopic slits and possibly other field masks.

It should contain an open position. A user can define a non-standard slit by directly using the Aperture effect.

Parameters

slit_names
[list of str]

filename_format
[str] A f-string for the path to the slit files

current_slit
[str] Default name

Examples

This Effect assumes a folder full of ASCII files containing the edges of each slit. Each file should be names the same except for the slit's name or identifier.

This example assumes a folder `masks` containing the slit ASCII files with the naming convention: `slit_A.dat`, `slit_B.dat`, etc.

```
name: slit_wheel
class: SlitWheel
kwargs:
    slit_names:
        - A
        - B
        - C
    filename_format: "masks/slit_{}.dat
    current_slit: "C"
```

add_slit(*newslit*, *name=None*)

Add a slit to the SlitWheel.

Parameters

newslit
[Slit]

name
[string] Name to be used for the new slit. If `None`, a name from the newslit object is used.

apply_to(*obj*, ***kwargs*)

Use apply_to of current_slit.

change_slit(*slitname=None*)

Change the current slit.

property current_slit

Return the currently used slit.

fov_grid(*which='edges'*, ***kwargs*)

See parent docstring.

get_table()

Create a table of slits with centre position, width and length.

Width is defined as the extension in the y-direction, length in the x-direction. All values are in milliarcsec.

required_keys = {'current_slit', 'filename_format', 'slit_names'}

scopesim.effects.apertures.**make_aperture_polygon**(*left*, *right*, *top*, *bottom*, *angle*, *shape*, ***kwargs*)

scopesim.effects.apertures.**mask_from_coords**(*x*, *y*, *pixel_scale*)

scopesim.effects.apertures.**points_on_a_circle**(*n*, *x0=0*, *y0=0*, *dx=1*, *dy=1*, *offset=0*)

scopesim.effects.apertures.**rotate**(*x*, *y*, *x0*, *y0*, *angle*)

Rotate a line by *angle* [deg] around the point (*x0*, *y0*).

scopesim.effects.data_container module

class scopesim.effects.data_container.**DataContainer**(*filename=None*, *table=None*, *array_dict=None*, *cmds=None*, ***kwargs*)

Bases: object

A class to hold data files needed by all Effects objects.

Parameters

filename
[str] Path to file containing data. Accepted formats: ASCII table, FITS table, FITS image

table
[astropy.Table] An astropy Table containing data

array_dict
[dict] A dictionary out of which an astropy.Table object can be constructed.

kwargs
addition meta data

Notes

If a table is to be generated from an `array_dict` parameter, column units can be passed as keyword arguments (kwargs) using the following format:

```
Datacontainer(... , <column name>_unit="<unit string>")
```

where unit string is a string recognised by `astropy.units`. Any additional table meta-data can also be passed using this format.

Attributes

data
[astropy.Table, fits.HDUList] A generic property method which returns the data from the file. Any function calling this should be prepared to handle both data formats

meta
[dict] Contains all meta data read in from the file's header, and/or passed via kwargs.

table
[astropy.Table] If the file has a table format (ASCII of FITS) it is read in immediately and stored in `.table`

_file
[HDUList pointer] If the file is a FITS image or cube, the data is only read in when needed in order to save on memory usage. `._file` contains a pointer to the data open FITS file.

property data

get_data(*ext=0*, *layer=None*)

Return either a table or a ImageHDU object.

Note: Use this call for reading in individual FITS extensions.

The `.data` handle will read in **all** extensions and return an HDUList object

---

Parameters

ext
[int]

layer
[int] If the FITS extension is a data cube, layer corresponds to a slice from this cube of `<ImageHDU>.data[layer, :, :]`

Returns

data_set
[astropy.Table, fits.ImageHDU]

property is_fits

meta = None

validate(*etype*)

scopesim.effects.detector_list module

TBA.

class scopesim.effects.detector_list.**DetectorList**(***kwargs*)

Bases: *Effect*

A description of detector positions and properties.

The list of detectors must have the following table columns

```
id   x_cen   y_cen  x_size  y_size  pixel_size  angle    gain
```

where:

- "id" is a reference id for the chip (fits header EXTNAME)
- "x_cen" and "y_cen" [mm] are the physical coordinates of centre of the chip on the detector plane
- "x_size", "y_size" [mm, pixel] are the width/height of the chip
- "pixel_size" [mm] is the physical size of pixels in the detector
- "angle" [deg] is the rotation of the detector relative to the x-axis
- "gain" [e-/ADU] is the conversion factor for electrons (photons) to ADUs

The units for each column (except `id`) must be given in the meta data using the format `<colname>_unit`. E.g. `x_size_unit`. See examples below.

Note: Currently only the units specified below are accepted.

For `x(y)_size_unit`, acceptable units are `mm`, `pixel`

Parameters

filename
[str, optional] Filename of the ASCII file with the detector description. See examples

array_dict
[dict] Dict containing the detector description. See examples

image_plane_id
[int] Which image plane the detector will look at (generally 0)

Examples

With the `array_dict` feature

```
-   name: single_detector
    class: DetectorList
    kwargs:
        image_plane_id : 0
        array_dict:
            id: [1]
            x_cen: [0.]
            y_cen: [0.]
            x_size: [5.12]
            y_size: [5.12]
            pixel_size: [0.01]
            angle: [0.]
            gain: [1.0]
        x_cen_unit: mm
        y_cen_unit: mm
        x_size_unit: mm
        y_size_unit: mm
        pixel_size_unit: mm
        angle_unit: deg
        gain_unit: electron/adu
```

Or referring to a table contained in a seperate ASCII file

```
- name : full_detector_array
  class : DetectorList
  kwargs :
    filename : "detecotr_list.dat"
    active_detectors : [1, 3]
    image_plane_id : 0
```

where the file detector_list.dat contains the following information

```
# x_cen_unit : mm
# y_cen_unit : mm
# x_size_unit : pix
# y_size_unit : pix
# pixel_size_unit : mm
# angle_unit : deg
# gain_unit : electron/adu
#
id   x_cen   y_cen  x_size  y_size  pixel_size  angle    gain
1   -63.94    0.00    4096    4096       0.015    0.0     1.0
2     0.00    0.00    4096    4096       0.015   90.0     1.0
3    63.94    0.00    4096    4096       0.015  180.0     1.0
```

property active_table

apply_to(*obj*, ***kwargs*)

TBA.

detector_headers(*ids=None*)

fov_grid(*which='edges'*, ***kwargs*)

Return an ApertureMask object. kwargs are "pixel_scale" [arcsec].

property image_plane_header

property image_plane_id: int

Get ID of the corresponding image plane.

plot(*axes=None*)

class scopesim.effects.detector_list.**DetectorWindow**(*pixel_size*, *x*, *y*, *width*, *height=None*, *angle=0*, *gain=1*, *units='mm'*, ***kwargs*)

Bases: *DetectorList*

For when a full DetectorList if too cumbersome.

Parameters

pixel_size
[float] [mm pixel-1] Physical pixel size

x, y
[float] [mm] Position of window centre relative to optical axis

width, height=None
[float] [mm] Dimensions of window. If height is None, height=width

angle
[float, optional] [deg] Rotation of window

gain
[float, optional] [ADU/e-]

units
[str, optional] [mm, pixel] Default "mm". Sets the input parameter units. If `"pixel"`, (`x`, `y`, `width`, `height`) are multiplied by `pixel_size`

scopesim.effects.effects module

Contains base class for effects.

class scopesim.effects.effects.**Effect**(*filename=None*, ***kwargs*)

Bases: *DataContainer*

Base class for representing the effects (artifacts) in an optical system.

The `Effect` class is conceived to independently apply the changes that an optical component (or series thereof) has on an incoming 3D description of an on-sky object. In other words, **an Effect object should receive a derivative of a ``Source`` object, alter it somehow, and return it**.

The interface for the Effect base-class has been kept very general so that it can easily be sub-classed as data for new effects becomes available. Essentially, a sub-classed Effects object must only contain the following attributes:

- `self.meta` - a dictionary to contain metadata.
- `self.apply_to(obj, **kwargs)` - a method which accepts a Source-derivative and returns an instance of the same class as `obj`
- `self.fov_grid(which="", **kwargs)`

  Parameters

  See :class:`DataContainer` for input parameters

`apply_to`(*obj*, ***kwargs*)

TBA.

`property display_name`

`fov_grid`(*which=''*, ***kwargs*)

Return the edges needed to generate FieldOfViews for an observation.

Parameters

which
[str] ["waveset", "edges", "shifts"] where: * waveset - wavelength bin extremes * edges - on sky coordinate edges for each FOV box * shifts - wavelength dependent FOV position offsets

Returns

waveset
[list] [um] N+1 wavelengths that set edges of N spectral bins

edges
[list of lists] [arcsec] Contains a list of footprint lists

shifts
[list of 3 lists] [wave, dx, dy] Contains lists corresponding to the (dx, dy) offset from the optical axis (0, 0) induced for each wavelength in (wave) [um, arcsec, arcsec]

`property include`

`info`()

Print basic information on the effect, notably the description.

`property meta_string`

`report`(*filename=None*, *output='rst'*, *rst_title_chars='*+'*, ***kwargs*)

For Effect objects, generates a report based on the data and meta-data.

This is to aid in the automation of the documentation process of the instrument packages in the IRDB.

Note: If the Effect can generate a plot, this will be saved to disc

---

Parameters

filename
[str, optional] Where to save the RST file

output
[str, optional] ["rst", "latex"] Output file format

rst_title_chars
[2-str, optional] Two unique characters used to denote rst subsection headings. Options: = - ` : ‘ “ ~ ^ _ * + # < >

Returns

rst_str
[str] The full reStructureText string

Notes

The format of the RST output is as follows:

```
<ClassType>: <effect name>
**************************
File Description: <description for file meta data>
Class Description: <description from class docstring>
Changes: <list of changes from file meta data>

Data
++++
.. figure:: <Figure_name>.png
    If the <Effect> object contains a ``.plot()`` function, add
    plot and write it to disc
Figure caption

Table caption
Table
    If the <Effect> object contains a ``.table()`` function, add
    a pprint version of the table

Meta-data
+++++++++
::
    A code block print out of the ``.meta`` dictionary
```

required_keys = {}

update(***kwargs*)

scopesim.effects.effects_utils module

TBA.

scopesim.effects.effects_utils.**combine_surface_effects**(*surface_effects*)

scopesim.effects.effects_utils.**empty_surface_list**(***kwargs*)

scopesim.effects.effects_utils.**get_all_effects**(*effects*, *effect_class*)

scopesim.effects.effects_utils.**is_spectroscope**(*effects*)

scopesim.effects.effects_utils.**make_effect**(*effect_dict*, *cmds=None*, ***properties*)

scopesim.effects.effects_utils.**scopesim_effect_classes**(*base_effect=<class 'scopesim.effects.effects.Effect'>*)

scopesim.effects.effects_utils.**z_order_in_range**(*z_eff*, *z_range: range*) → bool

Return True if any of the z_orders in *z_eff* is in the given range.

The *z_range* parameter can be constructed as `range(z_min, z_max)`.

Parameters

z_eff
[int or list of ints] z_order(s) of the effect.

z_range
[range] range object of allowed z_order values.

Returns

bool
True if at least one z_order is in range, False otherwise.

scopesim.effects.electronic module

Electronic detector effects - related to detector readout.

Classes: - DetectorModePropertiesSetter - set parameters for readout mode - AutoExposure - determine DIT and NDIT automatically - SummedExposure - simulates a summed stack of `ndit` exposures - PoorMansHxRGReadoutNoise - simple readout noise for HAWAII detectors - BasicReadoutNoise - readout noise - ShotNoise - realisation of Poissonian photon noise - DarkCurrent - add dark current - LinearityCurve - apply detector (non-)linearity and saturation - ReferencePixelBorder - BinnedImage - UnequalBinnedImage - Bias - adds constant bias level to readout

Functions: - make_ron_frame - pseudo_random_field

class scopesim.effects.electronic.**AutoExposure**(***kwargs*)

Bases: *Effect*

Determine DIT and NDIT automatically from ImagePlane.

DIT is determined such that the maximum value in the incident photon flux (including astronomical source, sky and thermal backgrounds) fills the full well of the detector (`!DET.full_well`) to a given fraction (`!OBS.autoexposure.fill_frac`). NDIT is determined such that `DIT` * `NDIT` results in the requested exposure time.

The requested exposure time is taken from `!OBS.exptime`.

The effects sets the parameters *!OBS.dit* and *!OBS.ndit*.

Examples

The parameters *!OBS.exptime*, *!DET.full_well* and *!DET.mindit* should be defined as properties in the respective subsections.

```
name: auto_exposure
description: automatic determination of DIT and NDIT
class: AutoExposure
include: True
kwargs:
    fill_frac: "!OBS.auto_exposure.fill_frac"
```

apply_to(*obj*, ***kwargs*)

TBA.

estimate_dit_ndit(*exptime: float*, *image_plane_max: float*, ***kwargs*) → tuple[float, int]

Automatically determine DIT and NDIT from exposure time.

Parameters

exptime
[float] Exposure time in seconds.

image_plane_max
[float] Maximum pixel value from image plane, used to avoid saturation.

Returns

dit
[float] Detector Integration Time.

ndit
[int] Number of Integrations.

required_keys = {'fill_frac', 'full_well', 'mindit'}

class scopesim.effects.electronic.**BasicReadoutNoise**(***kwargs*)

Bases: *Effect*

Readout noise computed as: ron * sqrt(NDIT).

apply_to(*det*, ***kwargs*)

TBA.

plot(*det*)

plot_hist(*det*, ***kwargs*)

required_keys = {'ndit', 'noise_std'}

class scopesim.effects.electronic.**Bias**(***kwargs*)

Bases: *Effect*

Adds a constant bias level to readout.

apply_to(*obj*, ***kwargs*)

TBA.

required_keys = {'bias'}

class scopesim.effects.electronic.**BinnedImage**(***kwargs*)

Bases: *Effect*

apply_to(*det*, ***kwargs*)

TBA.

required_keys = {'bin_size'}

class scopesim.effects.electronic.**DarkCurrent**(***kwargs*)

Bases: *Effect*

required: dit, ndit, value

apply_to(*obj*, ***kwargs*)
TBA.

plot(*det*, ***kwargs*)

required_keys = {'dit', 'ndit', 'value'}

class scopesim.effects.electronic.**DetectorModePropertiesSetter**(***kwargs*)

Bases: *Effect*

Set mode specific curr_sys properties for different detector readout modes.

A little class (`DetectorModePropertiesSetter`) that allows different `"!DET"` properties to be set on the fly.

Parameters

mode_properties
[dict] A dictionary containing the DET parameters to be changed for each mode. See below for an example yaml entry.

Examples

Add the values for the different detector readout modes to all the relevant detector yaml files. In this case the METIS HAWAII (L, M band) and GeoSnap (N band) detectors: METIS_DET_IMG_LM.yaml , METIS_DET_IMG_N.yaml

```
- name: lm_detector_readout_parameters
  class: DetectorModePropertiesSetter
  kwargs:
    mode_properties:
      fast:
        mindit: 0.04
        full_well: !!float 1e5
        ron: 70
      slow:
        mindit: 1.3
        full_well: !!float 1e5
        ron: 14
```

Add the OBS dict entry !OBS.detector_readout_mode to the properties section of the mode_yamls descriptions in the default.yaml files.

```
mode_yamls:
  - object: observation
    alias: OBS
    name: lss_l
    yamls:
      ...
    properties:
      ...
      detector_readout_mode: slow
```

apply_to(*obj*, ***kwargs*)
TBA.

list_modes()

Return list of available detector modes.

required_keys = {'mode_properties'}

select_mode(*obj*, ***kwargs*)

Automatically select detector mode based on image plane peak value.

Select the mode with lowest readnoise that does not saturate the detector. When all modes saturate, select the mode with the lowest saturation level (peak to full_well).

class scopesim.effects.electronic.**LinearityCurve**(***kwargs*)

Bases: *Effect*

Detector linearity effect.

The detector linearity curve is set in terms of *incident* flux (e/s) and *measured* detector values (ADU).

Examples

The effect can be instantiated in various ways.:

```
- name: detector_linearity
  class: LinearityCurve
  kwargs:
    filename: FPA_linearity.dat

- name: detector_linearity
  class: LinearityCurve
  kwargs:
    array_dict: {incident: [0, 77000, 999999999999],
                 measured: [0, 77000, 77000]}

- name: detector_linearity
  class: LinearityCurve
  kwargs:
    incident: [0, 77000, 99999999]
    measured: [0, 77000, 77000]
```

apply_to(*obj*, ***kwargs*)

TBA.

plot(***kwargs*)

required_keys = {'ndit'}

class scopesim.effects.electronic.**PoorMansHxRGReadoutNoise**(***kwargs*)

Bases: *Effect*

apply_to(*det*, ***kwargs*)

TBA.

plot(*det*, ***kwargs*)

plot_hist(*det*, ***kwargs*)

required_keys = {'n_channels', 'ndit', 'noise_std'}

class scopesim.effects.electronic.**Quantization**(***kwargs*)

Bases: *Effect*

Converts raw data to whole photons.

apply_to(*obj*, ***kwargs*)

TBA.

class scopesim.effects.electronic.**ReferencePixelBorder**(***kwargs*)

Bases: *Effect*

apply_to(*implane*, ***kwargs*)

TBA.

plot(*implane*, ***kwargs*)

class scopesim.effects.electronic.**ShotNoise**(***kwargs*)

Bases: *Effect*

apply_to(*det*, ***kwargs*)

TBA.

plot(*det*)

plot_hist(*det*, ***kwargs*)

class scopesim.effects.electronic.**SummedExposure**(***kwargs*)

Bases: *Effect*

Simulates a summed stack of `ndit` exposures.

apply_to(*obj*, ***kwargs*)

TBA.

required_keys = {'dit', 'ndit'}

class scopesim.effects.electronic.**UnequalBinnedImage**(***kwargs*)

Bases: *Effect*

apply_to(*det*, ***kwargs*)

TBA.

required_keys = {'binx', 'biny'}

scopesim.effects.electronic.**make_ron_frame**(*image_shape*, *noise_std*, *n_channels*, *channel_fraction*, *line_fraction*, *pedestal_fraction*, *read_fraction*)

scopesim.effects.electronic.**pseudo_random_field**(*scale=1*, *size=(1024, 1024)*)

scopesim.effects.fits_headers module

class scopesim.effects.fits_headers.**EffectsMetaKeywords**(*cmds=None*, ***kwargs*)

Bases: *ExtraFitsKeywords*

Adds meta dictionary info from all Effects to the FITS headers.

Parameters

ext_number
[int, list of ints, optional] Default 0. The numbers of the extensions to which the header keywords should be added

add_excluded_effects
[bool, optional] Default False. Add meta dict for effects with `<effect>.include=False`

keyword_prefix
[str, optional] Default "HIERARCH SIM". Custom FITS header keyword prefix. Effect meta dict entries will appear in the header as: `<keyword_prefix> EFFn <key> : <value>`

Examples

Yaml file entry:

```
name: effect_dumper
class: EffectsMetaKeywords
description: adds all effects meta dict entries to the FITS header
kwargs:
  ext_number: [0, 1]
  add_excluded_effects: False
  keyword_prefix: HIERARCH SIM
```

apply_to(*hdul*, ***kwargs*)

See parent docstring.

class scopesim.effects.fits_headers.**ExtraFitsKeywords**(*cmds=None*, ***kwargs*)

Bases: *Effect*

Extra FITS header keywords to be added to the pipeline FITS files.

These keywords are ONLY for keywords that should be MANUALLY ADDED to the headers after a simulation is read-out by the detector.

Simulation parameters (Effect kwargs values, etc) will be added automatically by ScopeSim in a different function, but following this format.

The dictionaries should be split into different HIERARCH lists, e.g.:

- HIERARCH ESO For ESO specific keywords
- HIERARCH SIM For ScopeSim specific keywords, like simulation parameters
- HIERARCH MIC For MICADO specific keywords, (unsure what these would be yet)

More HIERARCH style keywords can also be added as needed for other use-cases.

Parameters

filename
[str, optional] Name of a .yaml nested dictionary file. See below for examples

yaml_string
[str, optional] A triple-" string containing the contents of a yaml file

header_dict
[nested dicts, optional] A series of nested python dictionaries following the format of the examples below. This keyword allows these dicts to be definied directly in the Effect yaml file, rather than in a seperate header keywords file.

Examples

Specifying the extra FITS keywords directly in the .yaml file where the Effect objects are described.

```
name: extra_fits_header_entries
class: ExtraFitsKeywords
kwargs:
  header_dict:
    - ext_type: PrimaryHDU
      keywords:
        HIERARCH:
          ESO:
            ATM:
              TEMPERAT: -5
```

The contents of `header_dict` can also be abstracted away into a seperate file, e.g. `extra_FITS_keys.yaml`. The file format is described below in detail below.

```
name: extra_fits_header_entries
class: ExtraFitsKeywords
kwargs:
  filename: extra_FITS_keys.yaml
```

The Effect can be added directly in an iPython session.

```
>>> hdr_dic = {"ext_type": "PrimaryHDU",
               "keywords":
                   {"HIERARCH":
                       {"SIM":
                           {"hello": world}
                       }
                   }
               }
>>> extra_keys = ExtraFitsKeywords(header_dict=hdr_dic)
>>> optical_train.optics_manager.add_effect(extra_keys)
```

apply_to(*hdul*, ***kwargs*)

Add extra fits keywords from a yaml file including !,#-stings.

Parameters

optical_train
[scopesim.OpticalTrain, optional] Used to resolve #-strings

class scopesim.effects.fits_headers.**SimulationConfigFitsKeywords**(*cmds=None*, ***kwargs*)

Bases: *ExtraFitsKeywords*

Adds parameters from all config dictionaries to the FITS headers.

Parameters

ext_number
[int, list of ints, optional] Default 0. The numbers of the extensions to which the header keywords should be added

resolve
[bool] Default True. If True, all !-strings and #-strings are resolved via `from_currsys` before being add to the header. If False, the unaltered !-strings or #-strings are added to the header.

keyword_prefix
[str, optional] Default "HIERARCH SIM". Custom FITS header keyword prefix. Effect meta dict entries will appear in the header as: `<keyword_prefix> SRCn <key> : <value>`

Examples

Yaml file entry:

```
name: source_descriptor
class: SimulationConfigFitsKeywords
description: adds info from all config dicts to the FITS header
kwargs:
  ext_number: [0]
  resolve: False
  keyword_prefix: HIERARCH SIM
```

apply_to(*hdul*, ***kwargs*)

See parent docstring.

class scopesim.effects.fits_headers.**SourceDescriptionFitsKeywords**(*cmds=None*, ***kwargs*)

Bases: *ExtraFitsKeywords*

Adds parameters from all Source fields to the FITS headers.

Parameters

ext_number
[int, list of ints, optional] Default 0. The numbers of the extensions to which the header keywords should be added

keyword_prefix
[str, optional] Default "HIERARCH SIM". Custom FITS header keyword prefix. Effect meta dict entries will appear in the header as: `<keyword_prefix> SRCn <key> : <value>`

Examples

Yaml file entry:

```
name: source_descriptor
class: SourceDescriptionFitsKeywords
description: adds info from all Source fields to the FITS header
kwargs:
  ext_number: [0]
  keyword_prefix: HIERARCH SIM
```

apply_to(*hdul*, ***kwargs*)

See parent docstring.

scopesim.effects.fits_headers.**flatten_dict**(*dic*, *base_key=''*, *flat_dict=None*, *resolve=False*, *optics_manager=None*, *cmds=None*)

Flattens nested yaml dictionaries into a single level dictionary.

Parameters

dic
[dict]

base_key
[str]

flat_dict
[dict, optional] Top-level dictionary for recursive calls

resolve
[bool] If True, resolves !-str via from_currsys and #-str via optics_manager

optics_manager
[scopesim.OpticsManager] Required for resolving #-strings

cmds
[UserCommands] To use for resolving !-strings

Returns

flat_dict
[dict]

scopesim.effects.fits_headers.**get_relevant_extensions**(*dic*, *hdul*)

scopesim.effects.metis_lms_trace_list module

SpectralTraceList and SpectralTrace for the METIS LM spectrograph.

class scopesim.effects.metis_lms_trace_list.**MetisLMSEfficiency**(***kwargs*)

Bases: *TERCurve*

Computes the grating efficiency (blaze function) for the METIS LMS.

The procedure is described in E-REP-ATC-MET-1016_1.0. For a given order (determined by the central wavelength) the grating efficiency is modelled as a squared sinc function of wavelength via the grating angle.

make_ter_curve(*wcal*, *wavelen=None*)

Compute the blaze function for the selected order.

class scopesim.effects.metis_lms_trace_list.**MetisLMSImageSlicer**(*filename*, *ext_id='Aperture List'*, ***kwargs*)

Bases: *ApertureMask*

Treats the METIS LMS image slicer as an aperture mask effect.

This helps in building a `FieldOfView` object that combines the spatial field of the slicer with the spectral range covered by the LMS setting.

The effect differs from its parent class `ApertureMask` in the initialisation from the *Aperture List* extension of the trace file *!OBS.trace_file*.

class scopesim.effects.metis_lms_trace_list.**MetisLMSSpectralTrace**(*hdulist*, *spslice*, *params*, ***kwargs*)

Bases: *SpectralTrace*

SpectralTrace for the METIS LM spectrograph.

compute_interpolation_functions()

Define the transforms between (xi, lam) and (x, y).

The LMS transforms actually operate on phase rather than wavelength, hence the necessity of defining pre- and posttransforms on the lam variable.

fov_grid()

Provide information on the source space volume required by the effect.

Returns

A dictionary with entries *wave_min* and *wave_max*, *x_min*, *y_min*, *x_max*, *y_max*. Spatial limits refer to the sky and are given in arcsec.

fp2sky(*fp_x*)

Convert position in FP2 to position on sky.

get_matrices()

Extract matrix from lms_dist_poly.txt.

Evaluate polynomial to obtain matrices A, B, AI and BI at grism angle given echelle order and slice number

Parameters

order
[int] Echelle order

spslice
[int] Slice number

angle
[float] Grism angle in degrees

Returns

dict of four np.arrays of shape (4, 4) each

get_waverange(*det_mm_lims*)

Determine wavelength range covered by spec. trace on image plane.

lam2phase(*lam*)

Convert wavelength to phase.

Phase is lam * order / (2 * grat_spacing).

Parameters

lam
[ndarray (float)] wavelength (um)

Returns

Phase
[ndarray]

phase2lam(*phase*)

Convert phase to wavelength.

Wavelength is phase * 2 * grat_spacing / order

Parameters

phase
[ndarray (float)] phase (dimensionless)

Returns

wavelength
[ndarray (um)]

sky2fp(*xi*)

Convert position in arcsec to position in FP2.

class scopesim.effects.metis_lms_trace_list.**MetisLMSSpectralTraceList**(***kwargs*)

Bases: *SpectralTraceList*

SpectralTraceList for the METIS LM spectrograph.

apply_to(*obj*, ***kwargs*)

See parent docstring.

make_spectral_traces()

Compute the transformations by interpolation.

rectify_cube(*hdulist*, *xi_min=None*, *xi_max=None*, *interps=None*, ***kwargs*)

Rectify an IFU observation into a data cube

The HDU list (or fits file) must have been created with the present OpticalTrain (or an identically configured one).

Parameters

hdulist
[str or fits.HDUList] an ifu observation created with the present OpticalTrain

xi_min, xi_max
[float [arcsec]] Spatial limits of the image slicer on the sky. For METIS LMS, these values need not be provided by the user.

interps
[list of interpolation functions] If provided, there must be one for each image extension in *hdulist*. The functions go from pixels to the images and can be created with, e.g., RectBivariateSpline.

scopesim.effects.metis_lms_trace_list.**echelle_setting**(*wavelength*, *grat_spacing*, *wcal_def*)

Determine optimal echelle rotation angle for wavelength.

Parameters

lambda
[float] central wavelength in microns

grat_spacing
[float] grating rule spacing in microns

wcal_def: fits.TableHDU, fits.BinTableHDU, Table, str
definition of the wavelength calibration parameters If str, interpreted as name of a fits file, with a table extension 'WCAL'.

Returns

a *dict* with entries

- ***Ord*: echelle order**
- ***Angle*: grism angle**
- ***Phase*: phase**

scopesim.effects.obs_strategies module

Effects describing observing strategies.

- ChopNodCombiner: simulate chop-nod cycle

class scopesim.effects.obs_strategies.**ChopNodCombiner**(***kwargs*)

Bases: *Effect*

Creates and combines 4 images for each of the chop/nod positions.

- AA : original position `(dx, dy) = (0, 0)`
- AB : chop position `(dx, dy) = chop_offsets`
- BA : nod position `(dx, dy) = nod_offsets`
- BB : chop-nod position `(dx, dy) = nod_offsets + chop_offsets`

Images are combined using:

```
im_combined = (AA - AB) - (BA - BB)
```

If no `nod_offset` is given, it is set to the inverse of `chop_offset`.

ChopNodCombiner is a detector effect and should be placed last in the detector yaml (after the noise effects).

apply_to(*obj*, ***kwargs*)

TBA.

required_keys = {'chop_offsets', 'pixel_scale'}

scopesim.effects.obs_strategies.**chop_nod_image**(*img*, *chop_offsets*, *nod_offsets=None*)

Create four copies and combine in chop-nod pattern.

scopesim.effects.psf_utils module

scopesim.effects.psf_utils.**cutout_kernel**(*image*, *fov_header*, *kernel_header=None*)

scopesim.effects.psf_utils.**get_bkg_level**(*obj*, *bg_w*)

Determine the background level of image or cube slices.

Returns a scalar if obj is a 2d image or a vector if obj is a 3D cube (one value for each plane). The method for background determination is decided by self.meta["bkg_width"]: If 0, the background is returned as zero (implying no background subtraction). If -1, the background is estimated as the median of the entire image (or cube plane). If positive, the background is estimated as the median of a frame of width *bkg_width* around the edges.

scopesim.effects.psf_utils.**get_psf_wave_exts**(*hdu_list*, *wave_key='WAVE0'*)

Return a dict of {extension : wavelength}.

Parameters

hdu_list

Returns

wave_set, wave_ext

scopesim.effects.psf_utils.**get_strehl_cutout**(*fov_header*, *strehl_imagehdu*)

scopesim.effects.psf_utils.**get_total_wfe_from_table**(*tbl*)

scopesim.effects.psf_utils.**make_strehl_map_from_table**(*tbl*, *pixel_scale=<Quantity 1. arcsec>*)

scopesim.effects.psf_utils.**nearest_index**(*x*, *x_array*)

scopesim.effects.psf_utils.**nmrms_from_strehl_and_wavelength**(*strehl: float*, *wavelength*, *strehl_hdu*, *plot=False*) → float

Return the wavefront error needed to make a PSF with desired strehl ratio.

Parameters

strehl
[float] [0.001, 1] Desired strehl ratio. Values 1<sr<100 will be scale to <1

wavelength
[float] [um]

strehl_hdu
[np.ndarray] 2D map of strehl ratio as a function of wavelength [um] and residual wavefront error [nm RMS]

plot
[bool]

Returns

nm
[float] [nm] residual wavefront error for generating an on-axis AnisoCADO PSF with the desired strehl ratio at a given wavelength

scopesim.effects.psf_utils.**rescale_kernel**(*image*, *scale_factor*, *spline_order*)

scopesim.effects.psf_utils.**rotational_blur**(*image*, *angle*)

Rotate and coadd an image over a given angle to imitate a blur.

Parameters

image
[array] Image to blur

angle
[float] [deg] Angle over which the image should be rotationally blurred

Returns

image_rot
[array] Blurred image

scopesim.effects.psf_utils.**round_kernel_edges**(*kernel*)

scopesim.effects.psf_utils.**sigma2gauss**(*sigma*, *x_size=15*, *y_size=15*)

scopesim.effects.psf_utils.**strehl2sigma**(*strehl*)

scopesim.effects.psf_utils.**wfe2gauss**(*wfe*, *wave*, *width=None*)

scopesim.effects.psf_utils.**wfe2strehl**(*wfe*, *wave*)

scopesim.effects.psfs module

class scopesim.effects.psfs.**AnalyticalPSF**(***kwargs*)

Bases: *PSF*

class scopesim.effects.psfs.**AnisocadoConstPSF**(***kwargs*)

Bases: *SemiAnalyticalPSF*

Makes a SCAO on-axis PSF with a desired Strehl ratio at a given wavelength.

To make the PSFs a map connecting Strehl, Wavelength, and residual wavefront error is required.

Parameters

filename
[str] Path to Strehl map with axes (x, y) = (wavelength, wavefront error).

strehl
[float] Desired Strehl ratio. Either percentage [1, 100] or fractional [1e-3, 1].

wavelength
[float] [um] The given strehl is valid for this wavelength.

psf_side_length
[int] [pixel] Default is 512. Side length of the kernel images.

offset
[tuple] [arcsec] SCAO guide star offset from centre (dx, dy).

rounded_edges
[bool] Default is True. Sets all halo values below a threshold to zero. The threshold is determined from the max values of the edge rows of the kernel image.

Other Parameters

convolve_mode
[str] ["same", "full"] convolution keywords from scipy.signal.convolve

Examples

Add an AnisocadoConstPSF with code:

```
from scopesim.effects import AnisocadoConstPSF
psf = AnisocadoConstPSF(filename="test_AnisoCADO_rms_map.fits",
                        strehl=0.5,
                        wavelength=2.15,
                        convolve_mode="same",
                        psf_side_length=512)
```

Add an AnisocadoConstPSF to a yaml file:

```
effects:
-   name: Ks_Stehl_40_PSF
    description: A 40% Strehl PSF over the field of view
    class: AnisocadoConstPSF
    kwargs:
        filename: "test_AnisoCADO_rms_map.fits"
        strehl: 0.5
        wavelength: 2.15
        convolve_mode: full
        psf_side_length: 512
```

get_kernel(*fov*)

property nmRms

plot(*obj=None*, ***kwargs*)

remake_kernel(*x*)

Remake the kernel based on either a pixel_scale of FieldOfView.

Parameters

x: float, FieldOfView
[um] if float

required_keys = {'filename', 'strehl', 'wavelength'}

property strehl_ratio

property wavelength

class scopesim.effects.psfs.**DiscretePSF**(***kwargs*)

Bases: *PSF*

class scopesim.effects.psfs.**FieldConstantPSF**(***kwargs*)

Bases: *DiscretePSF*

A PSF that is constant across the field.

For spectroscopy, a wavelength-dependent PSF cube is built, where for each wavelength the reference PSF is scaled proportional to wavelength.

get_kernel(*fov*)

Find nearest wavelength and build PSF kernel from file

make_psf_cube(*fov*)

Create a wavelength-dependent psf cube

plot()

required_keys = {'filename'}

class scopesim.effects.psfs.**FieldVaryingPSF**(***kwargs*)

Bases: *DiscretePSF*

TBA.

Parameters

sub_pixel_flag
[bool, optional]

flux_accuracy
[float, optional] Default 1e-3. Level of flux conservation during rescaling of kernel

apply_to(*fov*, ***kwargs*)
See parent docstring.

get_kernel(*fov*)

plot()

required_keys = {'filename'}

property strehl_imagehdu
The HDU containing the positional info for kernel layers.

class scopesim.effects.psfs.**GaussianDiffractionPSF**(*diameter*, ***kwargs*)
Bases: *AnalyticalPSF*

fov_grid(*which='waveset'*, ***kwargs*)
See parent docstring.

get_kernel(*fov*)

plot()

update(***kwargs*)

class scopesim.effects.psfs.**NonCommonPathAberration**(***kwargs*)
Bases: *AnalyticalPSF*

TBA.

Needed: pixel_scale Accepted: kernel_width, strehl_drift

fov_grid(*which='waveset'*, ***kwargs*)
See parent docstring.

get_kernel(*obj*)

plot()

required_keys = {'pixel_scale'}

property total_wfe

class scopesim.effects.psfs.**PSF**(***kwargs*)
Bases: *Effect*

apply_to(*obj*, ***kwargs*)
Apply the PSF.

fov_grid(*which='waveset'*, ***kwargs*)
See parent docstring.

get_kernel(*obj*)

plot(*obj=None*, ***kwargs*)

class scopesim.effects.psfs.**PoorMansFOV**(*pixel_scale*, *spec_dict*, *recursion_call=False*)

Bases: object

class scopesim.effects.psfs.**SeeingPSF**(*fwhm=1.5*, ***kwargs*)

Bases: *AnalyticalPSF*

Currently only returns gaussian kernel with a `fwhm` [arcsec].

Parameters

fwhm
[flaot] [arcsec]

get_kernel(*fov*)

plot()

class scopesim.effects.psfs.**SemiAnalyticalPSF**(***kwargs*)

Bases: *PSF*

class scopesim.effects.psfs.**Vibration**(***kwargs*)

Bases: *AnalyticalPSF*

Creates a wavelength independent kernel image.

get_kernel(*obj*)

required_keys = {'fwhm', 'pixel_scale'}

scopesim.effects.rotation module

Effects related to rotation of the field/CCD.

Classes: - RotateCCD - Rotates CCD by integer multiples of 90 degrees

class scopesim.effects.rotation.**Rotate90CCD**(***kwargs*)

Bases: *Effect*

Rotates CCD by integer multiples of 90 degrees.

rotations kwarg is number of counter-clockwise rotations

Author: Dave jones

apply_to(*obj*, ***kwargs*)
See parent docstring.

required_keys = {'rotations'}

scopesim.effects.shifts module

class scopesim.effects.shifts.**AtmosphericDispersion**(***kwargs*)

Bases: *Shift3D*

Used to generate the wavelength bins based on shifts due to the atmosphere.

Doesn't contain an `apply_to` function, but provides information through the `fov_grid` function.

get_table(***kwargs*)

Called by the fov_grid method of Shift3D.

Returns

tbl
[astropy.Table] A table with the columns - waves : [um] - dx, dy : [arcsec]

Notes

Success! Returns the same values as: http://gtc-phase2.gtc.iac.es/science/astroweb/atmosRefraction.php

required_keys = {'airmass', 'altitude', 'humidity', 'latitude', 'pixel_scale', 'pressure', 'pupil_angle', 'temperature'}

class scopesim.effects.shifts.**AtmosphericDispersionCorrection**(***kwargs*)

Bases: *Shift3D*

Alters the position on the detector for a FOV object (WCS_prefix="D").

Only acts on FOVs during the main effects loop in OpticalTrain. For the sake of computational efficiency, the ADC can be instructed to counteract the atmospheric diffraction during the OpticalTrain setup phase, by passing the kwarg: `quick_adc=True`

Parameters

kwargs

apply_to(*fov*, ***kwargs*)

See parent docstring.

fov_grid(*which='shifts'*, ***kwargs*)

See parent docstring.

plot()

required_keys = {'airmass', 'altitude', 'humidity', 'latitude', 'pixel_scale', 'pressure', 'pupil_angle', 'temperature', 'wave_mid'}

class scopesim.effects.shifts.**Shift3D**(***kwargs*)

Bases: *Effect*

apply_to(*obj*, ***kwargs*)

See parent docstring.

fov_grid(*which='shifts'*, ***kwargs*)

See parent docstring.

get_table(***kwargs*)

plot()

scopesim.effects.shifts.**atmospheric_refraction**(*lam*, *z0=60*, *temp=0*, *rel_hum=60*, *pres=750*, *lat=-24.5*, *h=3064*)

Compute atmospheric refraction.

The function computes the angular difference between the apparent position of a star seen from the ground and its true position.

Parameters

lam
[float, np.ndarray] [um] wavelength bin centres

z0
[float, optional] [deg] zenith distance. Default is 60 deg from zenith

temp
[float, optional] [deg C] ground temperature. Default is 0 deg C

rel_hum
[float, optional] [%] relative humidity. Default is 60%

pres
[float, optional] [millibar] air pressure. Default is 750 mbar

lat
[float, optional] [deg] latitude. Default set for Cerro Armazones: 24.5 deg South

h
[float, optional] [m] height above sea level. Default is 3064 m

Returns

ang
[float, np.ndarray] [arcsec] angle between real position and refracted position

References

See Stone 1996 and the review by S. Pedraz - http://www.caha.es/newsletter/news03b/pedraz/newslet.html

scopesim.effects.shifts.**get_pixel_border_waves_from_atmo_disp**(***kwargs*)

TBA.

Parameters

****kwargs**
[TYPE] DESCRIPTION.

Returns

wave_pixel_edges
[TYPE] DESCRIPTION.

shifts_angle_edges
[TYPE] DESCRIPTION.

scopesim.effects.shutter module

Contains the Shutter effect.

class scopesim.effects.shutter.**Shutter**(***kwargs*)

Bases: *Effect*

Simulate a closed shutter, useful for dark exposures.

apply_to(*obj*, ***kwargs*)

Set all pixels of image plane to zero.

scopesim.effects.spectral_efficiency module

Spectral grating efficiencies.

class scopesim.effects.spectral_efficiency.**SpectralEfficiency**(***kwargs*)

Bases: *Effect*

Applies the grating efficiency (blaze function) for a SpectralTraceList.

apply_to(*obj*, ***kwargs*)

Interface between FieldOfView and SpectralEfficiency.

get_efficiencies()

Read effciencies from file, returns a dictionary.

plot()

Plot the grating efficiencies.

scopesim.effects.spectral_trace_list module

Effect for mapping spectral cubes to the detector plane.

The Effect is called *SpectralTraceList*, it applies a list of *spectral_trace_list_utils.SpectralTrace* objects to a *FieldOfView*.

class scopesim.effects.spectral_trace_list.**SpectralTraceList**(***kwargs*)

Bases: *Effect*

List of spectral trace geometries for the detector plane.

Should work in concert with an ApertureList (or ApertureMask) object and a DetectorList object

Spectral trace patterns are to be kept in a `fits.HDUList` with one or more `fits.BinTableHDU` extensions, each one describing the geometry of a single trace. The first extension should be a `BinTableHDU` connecting the traces to the correct `Aperture` and `ImagePlane` objects.

The `fits.HDUList` objects can be loaded using one of these two keywords:

- `filename`: for on disk FITS files, or
- `hdulist`: for in-memory `fits.HDUList` objects

The format and contents of the extensions in the HDUList (FITS file) object is listed below

apply_to(*obj*, ***kwargs*)

Interface between `FieldOfView` and `SpectralTraceList`.

This is called twice: 1. During setup of the required FieldOfView objects, the SpectralTraceList is asked for the source space volumes that it requires (spatial limits and wavelength limits). 2. During "observation" the method is passed a single FieldOfView object and applies the mapping to the image plane to it. The FieldOfView object is associated to one SpectralTrace from the list, identified by meta["trace_id"].

property footprint

Return the footprint of the entire SpectralTraceList.

property image_plane_header

Create and return header for the ImagePlane.

make_spectral_traces()

Return a dictionary of spectral traces read in from a file.

plot(*wave_min=None*, *wave_max=None*, *axes=None*, ***kwargs*)

Plot every spectral trace in the spectral trace list.

Parameters

wave_min
[float, optional] Minimum wavelength, if any. If None, value from_currsys is used.

wave_max
[float, optional] Maximum wavelength, if any. If None, value from_currsys is used.

axes
[matplotlib axes, optional] The axes object to use for the plot. If None (default), a new figure with one axes will be created.

****kwargs**
[dict] Any other parameters passed along to the plot method of the individual spectral traces.

Returns

fig
[matplotlib figure] DESCRIPTION.

rectify_cube(*hdulist*)

Rectify traces and combine into a cube.

rectify_traces(*hdulist*, *xi_min=None*, *xi_max=None*, *interps=None*, ***kwargs*)

Create rectified 2D spectra for all traces in the list.

This method creates an HDU list with one extension per spectral trace, i.e. it essentially treats all traces independently. For the case of an IFU where the traces correspond to spatial slices for the same wavelength range, use method *rectify_cube* (not yet implemented).

Parameters

hdulist
[str or fits.HDUList] The result of scopesim readout()

xi_min, xi_max
[float [arcsec]] Spatial limits of the slit on the sky. This should be taken from the header of the hdulist, but this is not yet provided by scopesim. For the time being, these limits *must* be provided by the user.

interps
[list of interpolation functions] If provided, there must be one for each image extension in *hdulist*. The functions go from pixels to the images and can be created with, e.g. `RectBivariateSpline`.

update_meta()

Update fov related meta values.

The values describe the full extent of the spectral trace volume in wavelength and space

class scopesim.effects.spectral_trace_list.**SpectralTraceListWheel**(***kwargs*)

Bases: *Effect*

A Wheel-Effect object for selecting between multiple gratings/grisms.

See `SpectralTraceList` for the trace file format description.

Parameters

trace_list_names
[list] The list of unique identifiers in the trace filenames

filename_format
[str] `f-string` that directs scopesim to the folder containing the trace files. This can be a `!-string` if the trace names are shared with other `*Wheel` effect objects (e.g. a `FilterWheel`). See examples.

current_trace_list
[str] default trace file to use

kwargs
[key-value pairs] Addition keywords that are passed to the `SpectralTraceList` objects See SpectralTraceList docstring

Examples

A simplified YAML file example taken from the OSIRIS instrument package:

```
alias: INST
name: OSIRIS_LSS

properties:
  decouple_detector_from_sky_headers: True
  grism_names:
    - R300B
    - R500B
    - R1000B
    - R2500V

effects:
  - name: spectral_trace_wheel
    description: grism wheel contining spectral trace geometries
    class: SpectralTraceListWheel
    kwargs:
      current_trace_list: "!OBS.grating_name"
      filename_format: "traces/LSS_{}_TRACE.fits"
      trace_list_names: "!INST.grism_names"

  - name: grating_efficiency
    description: OSIRIS grating efficiency curves, piggybacking on FilterWheel
    class: FilterWheel
    kwargs:
      minimum_throughput: !!float 0.
      filename_format: "gratings/{}.txt"
      current_filter: "!OBS.grating_name"
      filter_names: "!INST.grism_names"
```

apply_to(*obj*, ***kwargs*)
Use apply_to of current trace list.

property current_trace_list

required_keys = {'current_trace_list', 'filename_format', 'trace_list_names'}

scopesim.effects.spectral_trace_list_utils module

Utility classes and functions for `SpectralTraceList`.

This module contains

- the definition of the *SpectralTrace* class. The visible effect should always be a *SpectralTraceList*, even if that contains only one *SpectralTrace*.
- the definition of the *XiLamImage* class
- utility functions for use with spectral traces

`class scopesim.effects.spectral_trace_list_utils.SpectralTrace(trace_tbl, cmds=None, **kwargs)`

Bases: `object`

Definition of one spectral trace.

A SpectralTrace describes the mapping of spectral slit coordinates to the focal plane. The class reads an order layout and fits several functions to describe the geometry of the trace.

Slit coordinates are: - xi : spatial position along the slit [arcsec] - lam : Wavelength [um] Focal plane coordinates are: - x, y : [mm]

`compute_interpolation_functions()`

Compute various interpolation functions between slit and focal plane.

Focal plane coordinates are *x* and *y*, in mm. Slit coordinates are *xi* (spatial coordinate along the slit, in arcsec) and *lam* (wavelength, in um).

`footprint(wave_min=None, wave_max=None, xi_min=None, xi_max=None)`

Return corners of rectangle enclosing spectral trace.

Parameters

wave_min, wave_max
[float [um], Quantity] Minimum and maximum wavelength to compute the footprint on. If *None*, use the full range that spectral trace is defined on. Float values are interpreted as microns.

xi_min, xi_max
[float [arcsec], Quantity] Minimum and maximum slit position on the sky. If *None*, use the full range that spectral trace is defined on. Float values are interpreted as arcsec.

`fov_grid()`

Provide information on the source space volume required by the effect.

Returns

A dictionary with entries *wave_min* and *wave_max*.
Spatial limits are determined by the *ApertureMask* effect
and are not returned here.

`map_spectra_to_focal_plane(fov)`

Apply the spectral trace mapping to a spectral cube.

The cube is contained in a FieldOfView object, which also has world coordinate systems for the Source (sky coordinates and wavelengths) and for the focal plane. The method returns a section of the fov image along with info on where this image lies in the focal plane.

plot(*wave_min=None*, *wave_max=None*, *xi_min=None*, *xi_max=None*, ***, *c='r'*, *axes=None*, *plot_footprint=True*, *plot_wave=True*, *plot_ctrlpnts=True*, *plot_outline=False*, *plot_trace_id=False*)

Plot control points (and/or footprint) of the SpectralTrace.

Parameters

wave_min
[float, optional] Minimum wavelength, if any.

wave_max
[float, optional] Maximum wavelength, if any.

xi_min
[float, optional] Minimum slit, if any.

xi_max
[float, optional] Maximum slit, if any.

c
[str, optional] Colour, any valid matplotlib colour string. The default is "r".

axes
[matplotlib axes, optional] The axes object to use for the plot. If None (default), a new figure with one axes will be created.

Returns

axes
[matplotlib axes] The axes object containing the plot.

Other Parameters

plot_footprint
[bool, optional] Plot a rectangle encompassing all control points, which may be larger than the area actually covered by the trace, if the trace is not exactly perpendicular to the detector. The default is True.

plot_wave
[bool, optional] Annotate the wavelength points. The default is True.

plot_ctrlpnts
[bool, optional] Plot the individual control points as makers. The default is True.

plot_outline
[bool, optional] Plot the smallest tetragon encompassing all control points. The default is False.

plot_trace_id
[bool, optional] Write the trace ID in the middle of the trace. The default is False.

rectify(*hdulist*, *interps=None*, *wcs=None*, ***kwargs*)

Create 2D spectrum for a trace.

Parameters

hdulist
[HDUList] The result of scopesim readout

interps
[list of interpolation functions] If provided, there must be one for each image extension in *hdulist*. The functions go from pixels to the images and can be created with, e.g., RectBivariateSpline.

wcs
[The WCS describing the rectified XiLamImage. This can be created] in a simple way from the fov included in the *OpticalTrain* used in the simulation run producing *hdulist*.

The WCS can also be set up via the following keywords:
bin_width
[float [um]] The spectral bin width. This is best computed automatically from the spectral dispersion of the trace.

wave_min, wave_max
[float [um]] Limits of the wavelength range to extract. The default is the the full range on which the *SpectralTrace* is defined. This may extend significantly beyond the filter window.

xi_min, xi_max
[float [arcsec]] Spatial limits of the slit on the sky. This should be taken from the header of the hdulist, but this is not yet provided by scopesim

property trace_id

Return the name of the trace.

class scopesim.effects.spectral_trace_list_utils.**Transform2D**(*matrix*, *pretransform_x=None*, *pretransform_y=None*, *posttransform=None*)

Bases: object

2-dimensional polynomial transform.

The class is instantiated from a m x n matrix A that contains the coefficients of the polynomial. Along rows, the power of x increases; along columns, the power of y increases, such that A[j, i] is the coefficient of x^i y^j.

The functions *pretransform_x* and *pretransform_y* can be used to transform the input variables before the matrix is applied. The function *posttransform* can be applied to the output after application of the matrix.

In Scopesim, a usecase for the pre- and post-transform functions is the METIS LMS, where the matrices are applied to phases while Scopesim operates on wavelengths. The functions to pass are *lam2phase* and *phase2lam*.

Parameters

matrix
[np.array] matrix of polynomial coefficients

pretransform_x
[function, tuple]

pretransform_y
[function, tuple] If not None, the function is applied to the input variable *x* or *y* before the actual 2D transform is computed

posttransform
[function, tuple] If not None, the function is applied to the output variable after the 2D transform is computed

When passed as a tuple, the first element is the function itself,
the second element is a dictionary of arguments to the function.
Example:
```
def rescale(x, scale=1.):
    return x * scale

pretransform_x = (rescale, {"scale": 0.5})
```

classmethod fit(*xin*, *yin*, *xout*, *degree=4*)

Determine polynomial fits.

gradient()

Compute the gradient of a 2d polynomial transformation.

class scopesim.effects.spectral_trace_list_utils.**XiLamImage**(*fov*, *dlam_per_pix*)

Bases: object

Class to compute a rectified 2D spectrum.

The class produces and holds an image of xi (relative position along the spatial slit direction) and wavelength lambda.

Parameters

fov
[FieldOfView]

dlam_per_pix
[a 1-D interpolation function from wavelength (in um) to] dispersion (in um/pixel); alternatively a number giving an average dispersion

scopesim.effects.spectral_trace_list_utils.**fill_zeros**(*x*)

Fill in zeros in a sequence with the previous non-zero number.

scopesim.effects.spectral_trace_list_utils.**fit2matrix**(*fit*)

Return coefficients from a polynomial fit as a matrix.

The Polynomial2D fits of degree n have coefficients for all i, j with i + j <= n. How would one rearrange those?

scopesim.effects.spectral_trace_list_utils.**get_affine_parameters**(*coords*)

Return rotation and shear for each MTC point along a SpectralTrace.

Parameters

coords
[dict of 2D arrays] Each dict entry ["x", "y", "s"] contains a [N, M] 2D array of coordinates, where:

- N is the number of points along the slit (e.g. ~5), and
- M is the number of positions along the trace (e.g. >100)

Returns

rotations
[array] [deg] Rotation angles for M positions along the Trace

shears
[array] [deg] Shear angles for M positions along the Trace

scopesim.effects.spectral_trace_list_utils.**make_image_interpolations**(*hdulist*, ***kwargs*)

Create 2D interpolation functions for images.

scopesim.effects.spectral_trace_list_utils.**rolling_median**(*x*, *n*)

Calculate the rolling median of a sequence for +/- n entries.

scopesim.effects.spectral_trace_list_utils.**xilam2xy_fit**(*layout*, *params*)

Determine polynomial fits of FPA position.

Fits are of degree 4 as a function of slit position and wavelength.

scopesim.effects.spectral_trace_list_utils.**xy2xilam_fit**(*layout*, *params*)

Determine polynomial fits of wavelength/slit position.

Fits are of degree 4 as a function of focal plane position

scopesim.effects.surface_list module

TBA.

class scopesim.effects.surface_list.**SurfaceList**(***kwargs*)

Bases: *TERCurve*

add_surface(*surface*, *name=None*, *position=-1*, *add_to_table=True*)

add_surface_list(*surface_list*, *prepend=False*)

property area

property emission

fov_grid(*which='waveset'*, ***kwargs*)

Return the edges needed to generate FieldOfViews for an observation.

Parameters

which
[str] [“waveset”, “edges”, “shifts”] where: * waveset - wavelength bin extremes * edges - on sky coordinate edges for each FOV box * shifts - wavelength dependent FOV position offsets

Returns

waveset
[list] [um] N+1 wavelengths that set edges of N spectral bins

edges
[list of lists] [arcsec] Contains a list of footprint lists

shifts
[list of 3 lists] [wave, dx, dy] Contains lists corresponding to the (dx, dy) offset from the optical axis (0, 0) induced for each wavelength in (wave) [um, arcsec, arcsec]

get_emission(*etendue*, *start=0*, *end=None*, *rows=None*, *use_area=False*)

get_throughput(*start=0*, *end=None*, *rows=None*)

Copied directly from radiometry_table.

property is_empty

plot(*which='x'*, *wavelength=None*, ***, *axes=None*, ***kwargs*)

Plot TER curves.

Parameters

which
[{“x”, “t”, “e”, “r”}, optional] “x” plots throughput. “t”,”e”,”r” plot trans/emission/refl. Can be a combination, e.g. “tr” or “tex” to plot each.

wavelength
[array_like, optional] Passed to TERCurve.plot() for each surface. The default is None.

axes
[matplotlib axes, optional] If given, plot into existing axes. The default is None.

Returns

fig
[matplotlib figure] Figure containing plots.

property surface

property throughput

scopesim.effects.ter_curves module

Transmission, emissivity, reflection curves.

class scopesim.effects.ter_curves.**ADCWheel**(*cmds=None*, ***kwargs*)

Bases: *Effect*

Wheel holding a selection of predefined atmospheric dispersion correctors.

apply_to(*obj*, ***kwargs*)

Use `apply_to` of current ADC.

change_adc(*adcname=None*)

Change the current ADC.

property current_adc

Return the currently used ADC.

get_table()

Create a table of ADCs with maximum throughput.

required_keys = {'adc_names', 'current_adc', 'filename_format'}

class scopesim.effects.ter_curves.**AtmosphericTERCurve**(***kwargs*)

Bases: *TERCurve*

class scopesim.effects.ter_curves.**DownloadableFilterCurve**(***kwargs*)

Bases: *FilterCurve*

required_keys = {'filename_format', 'filter_name'}

class scopesim.effects.ter_curves.**FilterCurve**(*cmds=None*, ***kwargs*)

Bases: *TERCurve*

Descripton TBA.

Parameters

position
[int, optional]

filter_name
[str, optional] `Ks` - corresponding to the filter name in the filename pattern

filename_format
[str, optional] `TC_filter_{}.dat`

Can either be created using the standard 3 options:
- ``filename``: direct filename of the filter curve
- ``table``: an ``astropy.Table``
- ``array_dict``: a dictionary version of a table: ``{col_name1: values, }``
or by passing the combination of ``filter_name`` and ``filename_format`` as kwargs. Here all filter file names follow a pattern (e.g. see above) and the ``{}`` are replaced by ``filter_name`` at run time. ``filter_name`` can also be a !bang string for a ``__currsys__`` entry: ``"!INST.filter_name"``

property center

property centre

fov_grid(*which='waveset'*, ***kwargs*)

Return the edges needed to generate FieldOfViews for an observation.

Parameters

which
[str] ["waveset", "edges", "shifts"] where: * waveset - wavelength bin extremes * edges - on sky coordinate edges for each FOV box * shifts - wavelength dependent FOV position offsets

Returns

waveset
[list] [um] N+1 wavelengths that set edges of N spectral bins

edges
[list of lists] [arcsec] Contains a list of footprint lists

shifts
[list of 3 lists] [wave, dx, dy] Contains lists corresponding to the (dx, dy) offset from the optical axis (0, 0) induced for each wavelength in (wave) [um, arcsec, arcsec]

property fwhm

class scopesim.effects.ter_curves.**FilterWheel**(***kwargs*)

Bases: *FilterWheelBase*

Wheel holding a selection of predefined filters.

Examples

```
name: filter_wheel
class: FilterWheel
kwargs:
    filter_names: []
    filename_format: "filters/{}.
    current_filter: "Ks"
```

required_keys = {'current_filter', 'filename_format', 'filter_names'}

class scopesim.effects.ter_curves.**FilterWheelBase**(***kwargs*)

Bases: *Effect*

Base class for Filter Wheels.

`add_filter`(*newfilter*, *name=None*)

Add a filter to the FilterWheel.

Parameters

newfilter
[FilterCurve]

name
[string] Name to be used for the new filter. If *None* a name from the newfilter object is used.

`apply_to`(*obj*, ***kwargs*)

Use apply_to of current filter.

`change_filter`(*filtername=None*)

Change the current filter.

`property current_filter`

`fov_grid`(*which='waveset'*, ***kwargs*)

Return the edges needed to generate FieldOfViews for an observation.

Parameters

which
[str] [“waveset”, “edges”, “shifts”] where: * waveset - wavelength bin extremes * edges - on sky coordinate edges for each FOV box * shifts - wavelength dependent FOV position offsets

Returns

waveset
[list] [um] N+1 wavelengths that set edges of N spectral bins

edges
[list of lists] [arcsec] Contains a list of footprint lists

shifts
[list of 3 lists] [wave, dx, dy] Contains lists corresponding to the (dx, dy) offset from the optical axis (0, 0) induced for each wavelength in (wave) [um, arcsec, arcsec]

`get_table`()

`plot`(*which='x'*, *wavelength=None*, ***, *axes=None*, ***kwargs*)

Plot TER curves.

Parameters

which
[{“x”, “t”, “e”, “r”}, optional] “x” plots throughput. “t”,”e”,”r” plot trans/emission/refl. Can be a combination, e.g. “tr” or “tex” to plot each.

wavelength
[array_like, optional] DESCRIPTION. The default is None.

axes
[matplotlib axes, optional] If given, plot into existing axes. The default is None.

Returns

fig
[matplotlib figure] Figure containing plots.

property surface

property throughput

class scopesim.effects.ter_curves.**PupilTransmission**(*transmission*, *cmds=None*, ***kwargs*)

Bases: *TERCurve*

Wavelength-independent transmission curve.

Use this class to describe a cold stop or pupil mask that is characterised by "grey" transmissivity. The emissivity is set to zero, assuming that the mask is cold.

update_transmission(*transmission*, ***kwargs*)

class scopesim.effects.ter_curves.**QuantumEfficiencyCurve**(***kwargs*)

Bases: *TERCurve*

class scopesim.effects.ter_curves.**SkycalcTERCurve**(***kwargs*)

Bases: *AtmosphericTERCurve*

Retrieve an atmospheric spectrum from ESO's skycalc server.

Examples

```
- name : skycalc_background
  class : SkycalcTERCurve
  kwargs :
    wunit : "!SIM.spectral.wave_unit"
    wmin : "!SIM.spectral.wave_min"
    wmax : "!SIM.spectral.wave_max"
    wdelta : 0.0001     # 0.1nm bin width
    outer : 1
    outer_unit : "m"
```

property include

load_skycalc_table()

query_server(***kwargs*)

class scopesim.effects.ter_curves.**SpanishVOFilterCurve**(***kwargs*)

Bases: *FilterCurve*

Pulls a filter transmission curve down from the Spanish VO filter service.

Parameters

observatory
[str]

instrument
[str]

filter_name
[str]

Examples

```
name: HAWKI-Ks
class: SpanishVOFilterCurve
kwargs:
    observatory : Paranal
    instrument : HAWKI
    filter_name : Ks
```

required_keys = {'filter_name', 'instrument', 'observatory'}

class scopesim.effects.ter_curves.**SpanishVOFilterWheel**(***kwargs*)

Bases: *FilterWheelBase*

A FilterWheel that loads all the filters from the Spanish VO service.

> **Warning:** This use `astropy.download_file(..., cache=True)`.

The filter transmission curves probably won't change, but if you notice discrepancies, try clearing the astropy cache:

```
>> from astropy.utils.data import clear_download_cache
>> clear_download_cache()
```

Parameters

observatory
[str]

instrument
[str]

current_filter
[str] Default filter name

include_str, exclude_str
[str] String sequences that can be used to include or exclude filter names which contain a certain string. E.g. GTC/OSIRIS has curves for `sdss_g` and `sdss_g_filter`. We can force the inclusion of only the filter curves by setting `list_include_str: "_filter"`.

Examples

```
name: svo_filter_wheel
class: SpanishVOFilterWheel
kwargs:
    observatory: "GTC"
    instrument: "OSIRIS"
    current_filter: "sdss_r_filter"
    include_str: "_filter"
```

required_keys = {'current_filter', 'instrument', 'observatory'}

class scopesim.effects.ter_curves.**TERCurve**(*filename=None*, ***kwargs*)

Bases: *Effect*

Transmission, Emissivity, Reflection Curve.

note:: This is basically an `Effect` wrapper for the
`SpectralSurface` object

Must contain a wavelength column, and one or more of the following: `transmission`, `emissivity`, `reflection`. Additionally, in the header there should be the following keywords: wavelength_unit

kwargs that can be passed:

```
"rescale_emission" : { "filter_name": str, "value": float, "unit": str}
```

Examples

Directly inside a YAML file description:

```
name: bogus_surface
class: TERCurve
kwargs:
    array_dict:
        wavelength: [0.3, 3.0]
        transmission: [0.9, 0.9]
        emission: [1, 1]
    wavelength_unit: um
    emission_unit: ph s-1 m-2 um-1
    rescale_emission:
        filter_name: "Paranal/HAWK.Ks"
        value: 15.5
        unit: ABmag
```

Indirectly inside a YAML file:

```
name: some_curve
class TERCurve
kwargs:
    filename: bogus_surface.dat
```

which references this ASCII file:

```
# name: bogus_surface
# wavelength_unit: um
wavelength  transmission    emissivity
0.3         0.9             0.1
3.0         0.9             0.1
```

apply_to(*obj*, ***kwargs*)

TBA.

property background_source

property emission

plot(*which='x'*, *wavelength=None*, ***, *axes=None*, ***kwargs*)

Plot TER curves.

Parameters

which
[{"x", "t", "e", "r"}, optional] "x" plots throughput. "t","e","r" plot trans/emission/refl. Can be a combination, e.g. "tr" or "tex" to plot each.

wavelength
[array_like, optional] Wavelength on x-axis, taken from currsys if None (default).

axes
[matplotlib axes, optional] If given, plot into existing axes. The default is None.

Returns

fig
[matplotlib figure] Figure containing plots.

property throughput

class scopesim.effects.ter_curves.**TopHatFilterCurve**(*cmds=None*, ***kwargs*)

Bases: *FilterCurve*

A simple Top-Hat filter profile.

Parameters

transmission
[float] [0..1] Peak transmission of filter

blue_cutoff, red_cutoff
[float] [um] Blue and Red cutoff wavelengths

wing_transmission
[float, optional] [0..1] Default 0. Wing transmission of filter outside the cutoff range

Examples

```
name: J_band_tophat
class: TopHatFilterCurve
kwargs:
    transmission : 0.9
    wing_transmission : 0.001
    blue_cutoff : 1.15
    red_cutoff : 1.35
```

required_keys = {'blue_cutoff', 'red_cutoff', 'transmission'}

class scopesim.effects.ter_curves.**TopHatFilterWheel**(***kwargs*)

Bases: *FilterWheelBase*

A selection of top-hat filter curves as defined in the input lists.

Parameters

filter_names: list of string
transmissions: list of floats
[0..1] Peak transmissions inside the cutoff limits

wing_transmissions: list of floats
[0..1] Wing transmissions outside the cutoff limits

blue_cutoffs: list of floats
[um]

red_cutoffs: list of floats
[um]

current_filter: str, optional
Name of current filter at initialisation. If no name is given, the first entry in *filter_names* is used by default.

Examples

```
name: top_hat_filter_wheel
class: TopHatFilterWheel
kwargs:
    filter_names: ["J", "H", "K"]
    transmissions: [0.9, 0.95, 0.85]
    wing_transmissions: [0., 0., 0.001]
    blue_cutoffs: [1.15, 1.45, 1.9]
    red_cutoffs: [1.35, 1.8, 2.4]
    current_filter: "K"
```

required_keys = {'blue_cutoffs', 'filter_names', 'red_cutoffs', 'transmissions', 'wing_transmissions'}

scopesim.effects.ter_curves_utils module

TBA.

scopesim.effects.ter_curves_utils.**add_edge_zeros**(*tbl*, *wave_colname*)

scopesim.effects.ter_curves_utils.**apply_throughput_to_cube**(*cube*, *thru*)

Apply throughput curve to a spectroscopic cube.

Parameters

cube
[ImageHDU] three-dimensional image, dimension 0 (in python convention) is the spectral dimension. WCS is required.

thru
[synphot.SpectralElement, synphot.SourceSpectrum]

Returns

cube
[ImageHDU, header unchanged, data multiplied with] wavelength-dependent throughput.

scopesim.effects.ter_curves_utils.**combine_two_spectra**(*spec_a*, *spec_b*, *action*, *wave_min*, *wave_max*)

Combine transmission and/or emission spectrum with a common waverange.

Spec_A is the source spectrum Spec_B is either the transmission or emission that should be applied

Parameters

spec_a
[synphot.SourceSpectrum]

spec_b
[synphot.SpectralElement, synphot.SourceSpectrum]

action: str
["multiply", "add"]

wave_min, wave_max
[quantity] [Angstrom]

Returns

new_source
[synphot.SourceSpectrum]

scopesim.effects.ter_curves_utils.**download_svo_filter**(*filter_name*, *return_style='synphot'*)

Query the SVO service for the true transmittance for a given filter.

Copied 1 to 1 from tynt by Brett Morris

Parameters

filter_name
[str] Name of the filter as available on the spanish VO filter service e.g: `Paranal/HAWKI.Ks`

return_style
[str, optional] Defines the format the data is returned - synphot: synphot.SpectralElement - table: astropy.table.Table - quantity: astropy.unit.Quantity [wave, trans] - array: np.ndarray [wave, trans], where wave is in Angstrom - vo_table : astropy.table.Table - original output from SVO service

Returns

filt_curve
[See return_style] Astronomical filter object.

scopesim.effects.ter_curves_utils.**download_svo_filter_list**(*observatory*, *instrument*, *short_names=False*, *include=None*, *exclude=None*)

Query the SVO service for a list of filter names for an instrument.

Parameters

observatory
[str] Name of the observatory as available on the spanish VO filter service e.g: `Paranal/HAWKI.Ks` –> Paranal

instrument
[str] Name of the instrument. Be careful of hyphens etc. E.g. "HAWK-I"

short_names
[bool] Default False. If True, the full SVO names (obs/inst.filt) are split to only return the (filt) part of the name

include, exclude: str
Each a string sequence for excluding or including specific filters E.g. GTC/OSIRIS has curves for `sdss_g` and `sdss_g_filter`. We can force the inclusion of only the filter curves by setting `include="_filter"`.

Returns

names
[list] A list of filter names

scopesim.effects.ter_curves_utils.**get_filter**(*filter_name*)

scopesim.effects.ter_curves_utils.**get_filter_effective_wavelength**(*filter_name*, *cmds=None*)

scopesim.effects.ter_curves_utils.**get_zero_mag_spectrum**(*system_name='AB'*)

scopesim.effects.ter_curves_utils.**scale_spectrum**(*spectrum*, *filter_name*, *amplitude*)

Scale a SourceSpectrum to a value in a filter.

Parameters

spectrum
[synphot.SourceSpectrum]

filter_name
[str] Name of a filter from - a local instrument package (available in `rc.__search_path__`) - a generic filter name (see `ter_curves_utils.FILTER_DEFAULTS`) - a spanish-vo filter service reference (e.g. `"Paranal/HAWKI.Ks"`)

amplitude
[`astropy.Quantity`, float] The value that the spectrum should have in the given filter. Acceptable astropy quantities are: - u.mag : Vega magnitudes - u.ABmag : AB magnitudes - u.STmag : HST magnitudes - u.Jy : Jansky per filter bandpass Additionally the `FLAM` and `FNU` units from `synphot.units` can be used when passing the quantity for `amplitude`:

Returns

spectrum
[synphot.SourceSpectrum] Input spectrum scaled to the given amplitude in the given filter

Examples

```
>>> from scopesim.source.source_templates import vega_spectrum
>>> from scopesim.effects.ter_curves_utils as ter_utils
>>>
>>> spec = vega_spectrum()
>>> vega_185 = ter_utils.scale_spectrum(spec, "Ks", -1.85 * u.mag)
>>> ab_0 = ter_utils.scale_spectrum(spec, "Ks", 0 * u.ABmag)
>>> jy_3630 = ter_utils.scale_spectrum(spec, "Ks", 3630 * u.Jy)
```

scopesim.effects.ter_curves_utils.**zero_mag_flux**(*filter_name*, *photometric_system*, *return_filter=False*)

Return the zero magnitude photon flux for a filter.

Acceptable filter names are those given in `scopesim.effects.ter_curves_utils.FILTER_DEFAULTS` or a string with an appropriate name for a filter in the Spanish-VO filter-service. Such strings must use the naming convention: observatory/instrument.filter. E.g: `paranal/HAWKI.Ks`, or `Gemini/GMOS-N.CaT`.

Parameters

filter_name
[str] Name of the filter - see above

photometric_system
[str] [“vega”, “AB”, “ST”] Name of the photometric system

return_filter
[bool, optional] If True, also returns the filter curve object

Returns

flux
[float] [PHOTLAM]

filt
[synphot.SpectralElement] If return_filter is True

Module contents

scopesim.optics package

Submodules

scopesim.optics.fov module

Defines FieldOfView class.

class scopesim.optics.fov.**FieldOfView**(*header*, *waverange*, *detector_header=None*, *cmds=None*, ***kwargs*)

Bases: *FieldOfViewBase*

A FOV is spectro-spatial volume cut out of a Source object.

Flux units after extracting the fields from the Source are in ph/s/pixel

The initial header should contain an on-sky WCS description: - CDELT-, CUNIT-, NAXIS- : for pixel scale and size (assumed CUNIT in deg) - CRVAL-, CRPIX- : for positioning the final image - CTYPE- : is assumed to be "RA—TAN", "DEC–TAN"

and an image-plane WCS description - CDELT-D, CUNIT-D, NAXISn : for pixel scale and size (assumed CUNIT in mm) - CRVAL-D, CRPIX-D : for positioning the final image - CTYPE-D : is assumed to be "LINEAR", "LINEAR"

The wavelength range is given by waverange

property background_fields
Return list of BG_SRC ImageHDU fields.

property corners
Return sky footprint, image plane footprint.

property cube_fields
Return list of non-BG_SRC ImageHDU fields with NAXIS=3.

property data
Return either hdu.data, image, cube, spectrum or None.

extract_from(*src*)
..assumption: Bandpass has been applied.

Note: Spectra are cut and copied from the original Source object. They are in original units. ph/s/pix comes in the make_**** methods

---

flatten()

If cube, collapse along first axis.

property image_fields

Return list of non-BG_SRC ImageHDU fields with NAXIS=2.

make_cube_hdu()

TBA.

Used for IFUs, slit spectrographs, and coherent MOSs (e.g.KMOS)

Returned cube units are `ph s-1 voxel-1`

Note: `self.make_cube()` does NOT store anything in `self.cube`

self.cube and self.make_cube() are deliberately kept seperately so that self.cube will not be accidently overwritten by a rogue call from an Effect object.

All Effect objects should specifically test whether `self.cube is None` before assigning a new cube it

---

The cube is made with these steps:

1. Make waveset and canvas cube:

```
if at least one cube:
    set waveset to equal largest cube waveset
else:
    make waveset from self.meta values
make canvas cube based on waveset of largest cube and NAXIS1,2 from fov.
↪header
```

2. Find Cube fields (see `FieldOfView._make_cube_cubefields()`).
3. Find Image fields (see `FieldOfView._make_cube_imagefields()`).
4. Find Table fields (see `FieldOfView._make_cube_tablefields()`).

`PHOTLAM = ph / (s * m2 * um)`. Original source fields are in units of:

- tables: (PHOTLAM in spectrum)
- images: arcsec-2 (PHOTLAM in spectrum)
- cubes: PHOTLAM arcsec-2

Warning: Input Images and Cubes should have units of PHOTLAM arcsec-2

Returns

canvas_cube_hdu
[fits.ImageHDU] [ph s-1 AA-1 arcsec-2] # as needed by SpectralTrace

make_image_hdu(*use_photlam=False*)

TBA.

Used for imaging.

Output image units are ph s-1 pixel-1

Note: `self.make_image()` does NOT store anything in `self.image`

See make_cube for an explanation

Make canvas image from NAXIS1,2 from fov.header

Parameters

use_photlam
[bool] Default False. Defines the flux units of the image pixels

Returns

image_hdu
[fits.ImageHDU] [ph s-1 pixel-1] or PHOTLAM (if use_photlam=True)

`make_spectrum()`

TBA.

This is needed for when we do incoherent MOS instruments. Each fibre doesn't care about the spatial information.

Returns

spec
[SourceSpectrum] [PHOTLAM]

`property pixel_area`

`property table_fields`

Return list of Table fields.

`property trace_id`

Return the name of the trace.

`view(hdu_type='image', sub_pixel=None, use_photlam=None)`

Force the self.fields to be viewed as a single object.

Parameters

sub_pixel
[bool]

hdu_type
[str] ["cube", "image", "spectrum"]

Returns

self.hdu
[fits.ImageHDU, synphot.SourceSpectrum]

`volume(wcs_prefix='')`

`property wavelength`

Return central wavelength in um.

`property waverange`

Return wavelength range in um [wave_min, wave_max].

`property waveset`

Return a wavelength vector in um.

scopesim.optics.fov_manager module

Influences.

Spectral: - Red and blue edges of full spectrum - Chunks of a large spectral range

Spatial: - On-sky borders of Detector Array - On-sky borders of Aperture Mask - Chunks of large on-sky area - Slit mask borders - Multiple slits for IFU, mirror-MOS - Multiple lenses for fibre-fed MOS - each Effect should submit a list of volumes

IFU spectroscopy depends on: - the tracelist - the list of apertures - the detector array borders - PSF wavelength granularity - Atmospheric dispersion

MOS spectroscopy depends on: - the tracelist - the list of apertures - Atmospheric dispersion - PSF wavelength granularity - the detector array borders

Long slit spectroscopy depends on: - the tracelist ra, dec, lam vol –> x, y area - the slit aperture - the detector array borders - PSF wavelength granularity - Atmospheric dispersion

Imaging dependent on: - Detector array borders - PSF wavelength granularity - Atmospheric dispersion

class scopesim.optics.fov_manager.**FOVManager**(*effects=None*, *cmds=None*, ***kwargs*)

Bases: object

A class to manage the (monochromatic) image windows covering the target.

Parameters

effects
[list of Effect objects] Passed from optics_manager.fov_setup_effects

property fov_footprints

property fovs

generate_fovs_list() → Iterator[*FieldOfView*]

Generate a series of FieldOfViews objects based self.effects.

Yields

Iterator[FieldOfView]
Generator-Iterator of FieldOfView objects.

class scopesim.optics.fov_manager.**FovVolumeList**(*initial_volume=None*)

Bases: *FOVSetupBase*, MutableSequence

List of FOV volumes for FOVManager.

extract(*axes*, *edges*, *aperture_id=None*)

Return new volumes from within all existing volumes.

This method DOES NOT alter the existing self.volumes list To include the returned volumes, add them to the self.volumes list

Parameters

axes
[list of either {“wave”, “x”, “y”}] Which axis (`list` of single `str`) or axes (`list[str]`) to use. Must be `list` in either case.

edges
[list, tuple of lists] Edge points for each axes listed

aperture_id
[int, optional] Default None. If `None`, extract from all volumes. If `int`, only extract from volumes with this *aperture_id* in the meta dict

Returns

new_vols
[list of dicts] A list of all new volumes extracted from existing volumes

Examples

::

```
>>> fvl = FovVolumeList()
>>> fvl.split("x", 0)
>>> new_vols = fvl.extract(axes=["wave"], edges=([0.5, 0.6], ))
>>> new_vols = fvl.extract(axes=["x", "y"], edges=([-1, 1], [0, 5]))
>>> new_vols = fvl.extract(axes=["x", "y", "wave"],
>>>                        edges=([-1, 1], [0, 5], [0.5, 0.6]))
>>> new_vols = fvl.extract(axes=["x", "y"], edges=([-1, 1], [0, 5]),
>>>                        aperture_id=1)
>>>
>>> fvl += [new_vols]
```

insert(*index*, *value*)

S.insert(index, value) – insert value before index

shrink(*axis*, *values*, *aperture_id=None*) → None

Trim axes to new min/max value(s).

- Loop through all volume dict
- Replace any entries where min < values.min
- Replace any entries where max > values.max

Parameters

axis
[{"wave", "x", "y"} or list thereof] Which axis (`str`) or axes (`list[str]`) to use.

values
[list of 2 floats] [min, max], [min, None], [None, max]

aperture_id
[int, optional] Default None. If `None`, shrink all volumes. If `int`, only shrink volumes with this `aperture_id` in the meta dict

Examples

::

```
>>> fvl = FovVolumeList()
>>> fvl.shrink(axis="wave", values=[3.0, 3.1])
>>> fvl.shrink(axis="wave", values=[2.9, 3.1], aperture_id=1)
>>> fvl.shrink(axis=["x", "y"], values=([-1, 1], [0, 5]))
```

split(*axis*, *value*, *aperture_id=None*) → None

Split the all volumes that include axis=value into two.

- Loop through all volume dict
- Find any entries where min < value < max
- Add two new entries with [min, value], [value, max]

Parameters

axis
[{"wave", "x", "y"}, or list thereof] Which axis (`str`) or axes (`list[str]`) to use.

value
[float, list of floats]

aperture_id
[int, optional] Default None. If `None`, split all volumes. If `int`, only split volumes with this `aperture_id` in the meta dict

Examples

::

```
>>> fvl = FovVolumeList()
>>> fvl.split(axis="wave", value=1.5)
>>> fvl.split(axis="wave", value=[3.0, 3.1])
>>> fvl.split(axis=["x", "y"], value=[0, 0])
>>> fvl.split(axis=["x", "y"], value=([-1, 1], 0))
>>> fvl.split(axis=["x", "y"], value=([-1, 1], [0, 5]))
>>> fvl.split(axis="wave", value=3.0, aperture_id=1)
>>> fvl.split(axis="wave", value=3.0, aperture_id=None)
```

write_string(*stream: TextIO*) → None

Write formatted string representation to I/O stream.

scopesim.optics.fov_manager_utils module

scopesim.optics.fov_manager_utils.**combine_wavesets**(**wavesets*)

Join and sorts several sets of wavelengths into a single 1D array.

Parameters

wavesets
[one or more iterables] A group of wavelength arrays or lists

Returns

wave_set
[np.ndarray] Combined set of wavelengths

scopesim.optics.fov_manager_utils.**get_3d_shifts**(*effects*, ***kwargs*)

Returns the total 3D shifts (x,y,lam) from a series of Shift3D objects

Parameters

effects
[list of Shift3D effects]

Returns

shift_dict
[dict] returns the x, y shifts for each wavelength in the fov_grid, where fov_grid contains the edge wavelengths for each spectral layer

Notes

Units returned by fov_grid(): - wavelength: [um] - x_shift, y_shift: [deg]

scopesim.optics.fov_manager_utils.**get_imaging_fovs**(*headers*, *waveset*, *shifts*, ***kwargs*)

Return a generator of `FieldOfView` objects.

Parameters

headers
[list of fits.Header objects] Headers giving spatial extent of each FOV region

waveset
[list of floats] [um] N+1 wavelengths for N spectral layers

shifts
[list of tuples (or actually arrays?)] [deg] x,y shifts w.r.t to the optical axis plane. N shifts for N spectral layers

Returns

fovs
[generator of `FieldOfView` objects]

scopesim.optics.fov_manager_utils.**get_imaging_headers**(*effects*, ***kwargs*)

Return a generator of Header objects for each of the FieldOfVIew objects.

Parameters

effects
[list of Effect objects] Should contain all effects which return a header defining the extent of their spatial coverage

Returns

hdrs
[generator of Header objects]

Notes

FOV headers use the return values from the `<Effect>.fov_grid()` method. The `fov_grid` dict must contain the entry `edges`

This may change in future versions of ScopeSim

`scopesim.optics.fov_manager_utils.`**`get_imaging_waveset`**(*effects_list*, ***kwargs*)

Returns the edge wavelengths for the spectral layers needed for simulation

Parameters

effects_list
[list of Effect objects]

Returns

wave_bin_edges
[list] [um] list of wavelengths

`scopesim.optics.fov_manager_utils.`**`get_spectroscopy_fovs`**(*headers*, *shifts*, *effects=None*, ***kwargs*)

Return a generator of `FieldOfView` objects.

`scopesim.optics.fov_manager_utils.`**`get_spectroscopy_headers`**(*effects*, ***kwargs*)

Return generator of Header objects.

scopesim.optics.fov_utils module

`scopesim.optics.fov_utils.`**`combine_imagehdu_fields`**(*fov_header*, *src*, *fields_indexes*, *wave_min*, *wave_max*, *area*, *wcs_suffix=''*, *cmds=None*)

Combine list of ImageHDUs into a single one bounded by the Header WCS.

Parameters

fov_header
[fits.Header] Header from the FieldOfView

src
[Source object]

fields_indexes
[list of ints] Which indexes from <Source>.fields to use

wave_min
[float] [deg] Blue spectral border

wave_max
[float] [deg] Red spectral border

area
[float] [m2] Area of the primary aperture

wcs_suffix
[str] Which coordinate system to use - "" for the on-sky coordinate system - "D" for the image-plane coordinate system

Returns

canvas_hdu
[fits.ImageHDU]

scopesim.optics.fov_utils.**combine_table_fields**(*fov_header*, *src*, *field_indexes*)

Combine list of Table objects into a single one bounded by the Header WCS.

Parameters

fov_header
[fits.Header] Header from a FieldOfView objects

src
[Source object]

field_indexes
[list of int]

Returns

tbl
[Table]

scopesim.optics.fov_utils.**extract_area_from_imagehdu**(*imagehdu*, *fov_volume*)

Extract the part of a `ImageHDU` that fits inside the *fov_volume*.

Parameters

imagehdu
[fits.ImageHDU] The field ImageHDU, either an image or a cube with wavelength [um]

fov_volume
[dict]

Contains {"xs": [xmin, xmax], "ys": [ymin, ymax],
"waves": [wave_min, wave_max], "xy_unit": "deg" or "mm", "wave_unit": "um"}

Returns

new_imagehdu
[fits.ImageHDU]

scopesim.optics.fov_utils.**extract_area_from_table**(*table*, *fov_volume*)

Extract the entries of a `Table` that fits inside the *fov_volume*.

Parameters

table
[fits.ImageHDU] The field ImageHDU, either an image of a wavelength [um] cube

fov_volume
[dict]

Contains {"xs": [xmin, xmax], "ys": [ymin, ymax],
"waves": [wave_min, wave_max], "xy_unit": "deg" or "mm", "wave_unit": "um"}

Returns

new_imagehdu
[fits.ImageHDU]

scopesim.optics.fov_utils.**extract_common_field**(*field*, *fov_volume*)

Extract the overlapping parts of a field within a FOV volume.

Parameters

field
[Table or ImageHDU]

fov_volume
[dict]

Contains {"xs": [xmin, xmax], "ys": [ymin, ymax],
"waves": [wave_min, wave_max], "xy_unit": "deg" or "mm", "wave_unit": "um"}

Returns

field_new
[Table or ImageHDU]

scopesim.optics.fov_utils.**extract_range_from_spectrum**(*spectrum*, *waverange*)

scopesim.optics.fov_utils.**get_cube_waveset**(*hdr*, *return_quantity=False*)

scopesim.optics.fov_utils.**is_field_in_fov**(*fov_header*, *field*, *wcs_suffix=''*)

Return True if Source.field footprint is inside the FieldOfView footprint.

Parameters

fov_header
[fits.Header] Header from a FieldOfView object

field
[[astropy.Table, astropy.ImageHDU]] Field object from a Source object

wcs_suffix
[str] ["S", "D"] Coordinate system: Sky or Detector

Returns

is_inside_fov
[bool]

scopesim.optics.fov_utils.**make_cube_from_table**(*table*, *spectra*, *waveset*, *fov_header*, *sub_pixel=False*)

Parameters

table: astropy.Table
spectra: dict
waveset: np.ndarray
fov_header: fits.Header
sub_pixel: bool, optional

Returns

cube: fits.ImageHDU
Units of ph/s/m2/bin –> should this be ph / (s * m2 * um)?

scopesim.optics.fov_utils.**make_flux_table**(*source_tbl*, *src*, *wave_min*, *wave_max*, *area*)

scopesim.optics.fov_utils.**sky2fp**(*header*, *xsky*, *ysky*)

Convert sky coordinates to image plane coordinated.

Parameters

header
[Header] Header of a FieldOfView object which contains two sets of WCS keywords

xsky, ysky
[float, array] [deg] The on-sky coordinated

Returns

xdet, ydet
[float, array] [mm] The coordinated on the image plane

scopesim.optics.image_plane module

class scopesim.optics.image_plane.**ImagePlane**(*header*, *cmds=None*, ***kwargs*)

Bases: *ImagePlaneBase*

A class to act as a canvas onto which to project *Source* images or tables.

Parameters

header
[*fits.Header*] Must contain a valid WCS

.. todo: Write the code to deal with a canvas larger than max_segment_size

Examples

```
from astropy.table import Table
from scopesim.optics import image_plane as imp

my_point_source_table = Table(names=["x", "y", "flux"],
                              data=[(0,  1,  2)*u.mm,
                                    (0, -5, 10)*u.mm,
                                    (100,50,25)*u.ph/u.s])

hdr = imp.make_image_plane_header([my_point_source_table],
                                  pixel_size=0.015*u.mm)
img_plane = imp.ImagePlane(hdr)
img_plane.add(my_point_source_table)

print(img_plane.image)
```

add(*hdus_or_tables*, *sub_pixel=None*, *spline_order=None*, *wcs_suffix=''*)

Add a projection of an image or table files to the canvas.

Note: If a Table is provided, it must include the following columns: *x_mm*, *y_mm*, and *flux*.

Units for the columns should be provided in the <Table>.unit attribute or as an entry in the table's meta dictionary using this syntax: <Table>.meta["<colname>_unit"] = <unit>.

For example:

```
tbl["x"].unit = u.arcsec   # or
tbl.meta[x_unit"] = "deg"
```

If no units are given, default units will be assumed. These are:

- *x*, *y*: *arcsec*
- *flux* : *ph / s / pix*

Parameters

hdus_or_tables
[*fits.ImageHDU* or *astropy.Table*] The input to be projected onto the image plane. See above.

sub_pixel
[bool, optional] Default is False. Dictates if point files should be projected with sub-pixel shifts or not. Accounting for sub-pixel shifts is approx. 5x slower.

spline_order
[int, optional] Order of spline interpolations used in `scipy.ndimage` functions `zoom` and `rotate`.

wcs_suffix
[str, optional] Default "". For sky coords - "" or "S", Detector coords - "D"

property data

property header

property image

view(*sub_pixel*)

scopesim.optics.image_plane_utils module

scopesim.optics.image_plane_utils.**add_imagehdu_to_imagehdu**(*image_hdu: ImageHDU*, *canvas_hdu: ImageHDU*, *spline_order: int = 1*, *wcs_suffix: str = ''*, *conserve_flux: bool = True*) → ImageHDU

Re-project one `fits.ImageHDU` onto another `fits.ImageHDU`.

..assumption:: of equal grid coordinate lengths

Parameters

image_hdu
[fits.ImageHDU] The `ImageHDU` which will be reprojected onto *canvas_hdu*

canvas_hdu
[fits.ImageHDU] The `ImageHDU` onto which the image_hdu should be projected. This must include a valid WCS

spline_order
[int, optional] Default is 1. The order of the spline interpolator used by the `scipy.ndimage` functions

wcs_suffix
[str or WCS] To determine which WCS to use. "" for sky HDUs and "D" for ImagePlane HDUs. Can also be `astropy.wcs.WCS` object.

conserve_flux
[bool] Default is True. Used when zooming and rotating to keep flux constant.

Returns

canvas_hdu
[fits.ImageHDU]

scopesim.optics.image_plane_utils.**add_table_to_imagehdu**(*table: Table*, *canvas_hdu: ImageHDU*, *sub_pixel: bool = True*, *wcs_suffix: str = ''*) → ImageHDU

Add files from an astropy.Table to the image of an fits.ImageHDU.

Parameters

table
[astropy.Table] Must contain the columns "x_mm", "y_mm", "flux" with the units in the column attribute .unit, or in the table.meta dictionary as "<colname>_unit". Default units are `mm` and `ph / s / pix`

canvas_hdu
[fits.ImageHDU] The ImageHDU onto which the table files should be projected. This must include a valid WCS

sub_pixel
[bool, optional] Default is True. If True, sub-pixel shifts of files will be taken into account when projecting onto the canvas pixel grid. This takes about 5x longer than ignoring the sub-pixel shifts

wcs_suffix
[str, optional]

Returns

canvas_hdu
[fits.ImageHDU]

scopesim.optics.image_plane_utils.**affine_map**(*input*, *matrix=None*, *rotation_angle: float = 0.0*, *shear_angle: float = 0.0*, *scale_factor=None*, *reshape: bool = True*, *spline_order: int = 3*)

Apply an affine transformation matrix to an image around its centre.

Similar functionality to `scipy.ndimage.rotate` but for the `affine_transformation` function

Either a 2x2 affine transformation matrix can be supplied, or the rotation, shear, and scaling values which are the basis of an affine transformation.

Parameters

input
[array_like] The input array

matrix
[ndarray, optional] A 2x2 affine transformation matrix

rotation_angle
[float, optional] [deg] If matrix==None, a rotation matrix is built from this angle

shear_angle
[float, optional] [deg] If matrix==None, a y-axis shear matrix is built from this angle

scale_factor
[list, array] [mx, my] If matrix==None, a scaling matrix is built from this list

reshape
[bool, optional] If True, the array is re-sized to contain the whole transformed image

spline_order
[int, optional] Default is 3. Spline interpolation order

Returns

output
[array-like] The new mapping of the image

scopesim.optics.image_plane_utils.**calc_footprint**(*header*, *wcs_suffix=''*, *new_unit: str = None*)

Return the sky/detector positions [deg/mm] of the corners of a header WCS.

TODO: The rest of this docstring is outdated, please update!

The positions returned correspond to the corners of the header's image array, in this order:

```
(ra, dec) = (0,0), (w, 0), (w, h), (0, h)
(x, y) = (0,0), (w, 0), (w, h), (0, h)
```

where `w`, `h` are equal to NAXIS1 and NAXIS2 from the header.

Parameters

header
[fits.Header]

wcs_suffix
[str] Letter suffix for the WCS keywords, e.g. CDELT1D for image-plane coords

Returns

x, y
[arrays of floats] [deg or mm] x are the coordinates for pixels [0, w, w, 0] [deg or mm] y are the coordinates for pixels [0, 0, h, h]

scopesim.optics.image_plane_utils.**calc_table_footprint**(*table: Table*, *x_name: str*, *y_name: str*, *tbl_unit: str*, *new_unit: str*, *padding=None*) → ndarray

Equivalent to `calc_footprint()`, but for tables instead of images.

Parameters

table
[astropy.table.Table] Table containing data.

x_name
[str] Name of the column in *table* to use as x-coordinates.

y_name
[str] Name of the column in *table* to use as y-coordinates.

tbl_unit
[str] Default unit to use for x and y if no units are found in *table*.

new_unit
[str] Unit to convert x and y to, can be identical to *tbl_unit*.

padding
[astropy.units.Quantity, optional] Constant value to subtract from minima and add to maxima. If used, must be Quantity with same physical type as x and y. If None (default), no padding is added.

Returns

extent
[(4, 2) array] Array containing corner points (clockwise from bottom left). Format and order are equivalent to the output of `astropy.wcs.WCS.calc_footprint()`.

scopesim.optics.image_plane_utils.**create_wcs_from_points**(*points: ndarray*, *pixel_scale: float*, *wcs_suffix: str = ''*) → tuple[astropy.wcs.wcs.WCS, numpy.ndarray]

Create *astropy.wcs.WCS* instance that fits all points inside.

Parameters

corners
[(N, 2) array] 2D array of N >= 2 points in the form of [x, y].

pixel_scale
[float] DESCRIPTION.

wcs_suffix
[str, optional] DESCRIPTION. The default is "".

Returns

new_wcs
[TYPE] Newly created WCS instance.

naxis
[TYPE] Array of NAXIS needed to fit all points.

scopesim.optics.image_plane_utils.**det_wcs_from_sky_wcs**(*sky_wcs: WCS*, *pixel_scale: float*, *plate_scale: float*, *naxis=None*) → tuple[astropy.wcs.wcs.WCS, numpy.ndarray]

Create detector WCS from celestial WCS using pixel and plate scales.

Parameters

sky_wcs
[astropy.wcs.WCS] Celestial WCS.

pixel_scale
[float] Quantity or float (assumed to be arcsec / pixel).

plate_scale
[float] Quantity or float (assumed to be arcsec / mm).

naxis
[(int, int), optional] Shape of the image, usually `NAXIS1` and `NAXIS2`. If the input WCS holds this information, the default None will use that. Otherwise not providing *naxis* will raise and error.

Returns

det_wcs
[astropy.wcs.WCS] Detector WCS.

det_naxis
[(int, int)] Shape of the image (`NAXIS1`, `NAXIS2`).

scopesim.optics.image_plane_utils.**get_canvas_header**(*hdu_or_table_list*, *pixel_scale=<Quantity 1. arcsec>*)

Generate a fits.Header with a WCS that covers everything in the FOV.

Parameters

hdu_or_table_list
[list] A list of Tables and/or ImageHDU py_objects

pixel_scale
[astropy.Quantity] [arcsec] The pixel scale of the projection. Default in 1 arcsec

Returns

header
[fits.Header] A Header containing a WCS and NAXISn values to build an ImageHDU

scopesim.optics.image_plane_utils.**header_from_list_of_xy**(*x*, *y*, *pixel_scale*, *wcs_suffix=''*, *arcsec=False*)

Make a header large enough to contain all x,y on-sky coordinates.

Parameters

x, y
[list of floats] [deg, mm] List of sky coordinates to be bounded by the NAXISn keys

pixel_scale
[float] [deg, mm]

Returns

hdr
[fits.Header]

scopesim.optics.image_plane_utils.**overlay_image**(*small_im*, *big_im*, *coords*, *mask=None*, *sub_pixel=False*)

Overlay small_im on top of big_im at the position specified by coords.

`small_im` will be centred at `coords`

Adapted from: `https://stackoverflow.com/questions/14063070/overlay-a-smaller-image-on-a-larger-image-`

scopesim.optics.image_plane_utils.**pix2val**(*header*, *x*, *y*, *wcs_suffix=''*)

Return the real coordinates [deg, mm] for coordinates from a Header WCS.

Parameters

header
[fits.Header]

x, y
[float, list, array]

wcs_suffix
[str]

Returns

a, b
[float, array] [deg, mm] Real coordinates as given by the Header WCS

scopesim.optics.image_plane_utils.**reorient_imagehdu**(*imagehdu: ImageHDU*, *wcs_suffix: str = ''*, *conserve_flux: bool = True*, *spline_order: int = 1*) → ImageHDU

Apply an affine transformation to the image, as given in its header.

Parameters

imagehdu
[fits.ImageHDU]

wcs_suffix
[str]

conserve_flux
[bool]

spline_order
[int] [1..5] Order of the spline interpolation used by `scipy.ndimage.rotate`

Returns

imagehdu
[fits.ImageHDU]

`scopesim.optics.image_plane_utils.`**`rescale_imagehdu`**(*imagehdu: ImageHDU*, *pixel_scale: float*, *wcs_suffix: str = ''*, *conserve_flux: bool = True*, *spline_order: int = 1*) → ImageHDU

Scale the .data array by the ratio of pixel_scale [deg] and CDELTn.

pixel_scale should NOT be passed as a Quantity!

Parameters

imagehdu
[fits.ImageHDU]

pixel_scale
[float] [deg] NOT to be passed as a Quantity

wcs_suffix
[str]

conserve_flux
[bool]

spline_order
[int] [1..5] Order of the spline interpolation used by `scipy.ndimage.rotate`

Returns

imagehdu
[fits.ImageHDU]

`scopesim.optics.image_plane_utils.`**`sky_wcs_from_det_wcs`**(*det_wcs: WCS*, *pixel_scale: float*, *plate_scale: float*, *naxis=None*) → tuple[astropy.wcs.wcs.WCS, numpy.ndarray]

Create celestial WCS from detector WCS using pixel and plate scales.

Parameters

det_wcs
[astropy.wcs.WCS] Detector WCS.

pixel_scale
[float] Quantity or float (assumed to be arcsec / pixel).

plate_scale
[float] Quantity or float (assumed to be arcsec / mm).

naxis
[(int, int), optional] Shape of the image, usually `NAXIS1` and `NAXIS2`. If the input WCS holds this information, the default None will use that. Otherwise not providing *naxis* will raise and error.

Returns

sky_wcs
[astropy.wcs.WCS] Celestial WCS.

sky_naxis
[(int, int)] Shape of the image (`NAXIS1`, `NAXIS2`).

`scopesim.optics.image_plane_utils.`**`split_header`**(*hdr*, *chunk_size*, *wcs_suffix=''*)

Split a header into many smaller parts of the chunk_size.

Parameters

hdr
chunk_size
wcs_suffix

Returns

hdr_list

`scopesim.optics.image_plane_utils.`**`sub_pixel_fractions`**(*x*, *y*)

Make a list of pixel coordinates and weights to reflect sub-pixel shifts.

A point source which isn't centred on a pixel can be modelled by a centred PSF convolved with a shifted delta function. A fraction of the delta function in moved into each of the adjoining pixels. For example, a star at `(x,y)=(0.2, 0.2)` would be represented by a following pixel weights:

```
---------------
| 0.16 | 0.04 |
---------------
| 0.64 | 0.16 |
---------------
```

where (0,0) is the centre of the bottom-left pixel

Given (x,y) pixel coordinates, this function returns the fractions of flux that should go into the surrounding pixels, as well as the coordinates of those neighbouring pixels.

Parameters

x, y
[float]

Returns

x_pix, y_pix, fracs
[list of (int, int, float)] The x and y pixel coordinates and their corresponding flux fraction

`scopesim.optics.image_plane_utils.`**`val2pix`**(*header*, *a*, *b*, *wcs_suffix=''*)

Return the pixel coordinates for real coordinates [deg, mm] from a WCS.

Parameters

header
[fits.Header]

a, b
[float, list, array] [deg, mm]

Returns

x, y
[float, array] [pixel] Pixel coordinates as given by the Header WCS

scopesim.optics.monochromatic_trace_curve module

class scopesim.optics.monochromatic_trace_curve.**MonochromeTraceCurve**(*x*, *y*, *s*, *wave_min*, *wave_max*, ***kwargs*)

Bases: object

Contains coordinates along a monochromatic section of a spectral trace.

Used to generate detector plane position WCS info for FOVs in spectral mode

get_header(*pixel_size*)

property header

scopesim.optics.optical_element module

class scopesim.optics.optical_element.**OpticalElement**(*yaml_dict=None*, *cmds=None*, ***kwargs*)

Bases: object

Contains all information to describe a section of an optical system.

There are 5 major section: `location`, `telescope`, `relay optics` `instrument`, `detector`.

An OpticalElement describes how a certain section of the optical train changes the incoming photon distribution by specifying a list of `Effects` along with a set of local properties e.g. temperature, etc which are common to more than one Effect

Parameters

yaml_dict
[dict] Description of optical section properties, effects, and meta-data

kwargs
[dict] Optical Element specific information which has no connection to the effects that are passed. Any global values, e.g. airmass (i.e. bang strings) are passed on to the individual effect which can extract the relevant bang_string from the UserCommands object held in self.cmds

Attributes

meta
[dict] Contains meta data from the yaml, and is updated with the OBS_DICT key-value pairs

properties
[dict] Contains any properties that is "global" to the optical element, e.g. instrument temperature, atmospheric pressure. Any OBS_DICT keywords are cleaned with from the `meta` dict during initialisation

effects
[list of dicts] Contains the a list of dict descriptions of the effects that the optical element

generates. Any OBS_DICT keywords are cleaned with from the `meta` dict during initialisation.

add_effect(*effect*)

property display_name

get_all(*effect_class*)

get_z_order_effects(*z_level: int*, *z_max: int = None*)

Yield all effects in the given 100-range of *z_level*.

E.g., `z_level=200` will yield all effect with a z_order between 200 and 299. Optionally, the upper limit can be set manually with the optional argument *z_max*.

Parameters

z_level
[int] 100-range of z_orders.

z_max
[int, optional] Optional upper bound. This is currently not used anywhere in ScopeSim, but the functionality is tested. If None (default), this will be set to `z_level + 99`.

Yields

eff
[Iterator of effects] Iterator containing all effect objects in the given z_order range.

Raises

TypeError
Raised if either *z_level* or *z_max* is not of int type.

ValueError
Raised if *z_max* (if given) is less than *z_level*.

list_effects()

property masks_list

pretty_str() → str

Return formatted string representation as str.

property properties_str

report(*filename=None*, *output='rst'*, *rst_title_chars='^#*+'*, ***kwargs*)

property surfaces_list

write_string(*stream: TextIO*, *list_effects: bool = True*) → None

Write formatted string representation to I/O stream.

scopesim.optics.optical_train module

class scopesim.optics.optical_train.**OpticalTrain**(*cmds=None*)

Bases: object

The main class for controlling a simulation.

Parameters

cmds
[UserCommands, str] If the name of an instrument is passed, OpticalTrain tries to find the instrument package, and internally creates the UserCommands object

Examples

Create an optical train:

```
>>> import scopesim as im
>>> cmd = sim.UserCommands("MICADO")
>>> opt = sim.OpticalTrain(cmd)
```

Observe a Source object:

```
>>> src = sim.source.source_templates.empty_sky()
>>> opt.observe(src)
>>> hdus = opt.readout()
```

List the effects modelled in an OpticalTrain:

```
>>> print(opt.effects)
```

Effects can be accessed by using the name of the effect:

```
>>> print(opt["dark_current"])
```

To include or exclude an effect during a simulation run, use the `.include` attribute of the effect:

```
>>> opt["dark_current"].include = False
```

Data used by an Effect object is contained in the `.data` attribute, while other information is contained in the `.meta` attribute:

```
>>> opt["dark_current"].data
>>> opt["dark_current"].meta
```

Meta data values can be set by either using the `.meta` attribute directly:

```
>>> opt["dark_current"].meta["value"] = 0.5
```

or by passing a dictionary (with one or multiple entries) to the OpticalTrain object:

```
>>> opt["dark_current"] = {"value": 0.75, "dit": 30}
```

property effects

`load`(*user_commands*)

(Re)Load an OpticalTrain with a new set of UserCommands.

Parameters

user_commands
[UserCommands or str]

`observe`(*orig_source*, *update=True*, ***kwargs*)

Main controlling method for observing `Source` objects.

Parameters

orig_source
[Source]

update
[bool] Reload optical system

kwargs
[expanded dict] Any keyword-value pairs from a config file

Notes

How the list of Effects is split between the 5 main tasks:

- Make a FOV list - z_order = 0..99
- Make a image plane - z_order = 100..199
- Apply Source altering effects - z_order = 200..299
- Apply FOV specific (3D) effects - z_order = 300..399
- Apply FOV-independent (2D) effects - z_order = 400..499
- [Apply detector plane (0D, 2D) effects - z_order = 500..599]

Todo: List is out of date - update

`prepare_source`(*source*)

Prepare source for observation.

The method is currently applied to cube fields only. The source data are converted to internally used units (PHOTLAM). The source data are interpolated to the waveset used by the FieldOfView This is necessary when the source data are sampled on a coarser grid than used internally, or if the source data are sampled on irregular wavelengths. For cube fields, the method assumes that the wavelengths at which the cube is sampled is provided explicitely as attribute *wave* if the cube ImageHDU.

`readout`(*filename=None*, ***kwargs*)

Produce detector readouts for the observed image.

Parameters

filename
[str, optional] Where to save the FITS file

kwargs

Returns

hdu
[fits.HDUList]

Notes

- Apply detector plane (0D, 2D) effects - z_order = 500..599

`report`()

`shutdown`()

Shut down the instrument.

This method closes all open file handles and should be called when the optical train is no longer needed.

`update`(***kwargs*)

Update the user-defined parameters and remake main internal classes.

Parameters

kwargs
[expanded dict] Any keyword-value pairs from a config file

`write_header`(*hdulist*)

Write meaningful header to simulation product.

`scopesim.optics.optical_train.`**`apply_fov_effects`**(*fov*, *fov_effects*)

`scopesim.optics.optical_train.`**`extract_source`**(*fov*, *source*)

`scopesim.optics.optical_train.`**`view_fov`**(*fov*, *hdu_type*)

scopesim.optics.optics_manager module

class `scopesim.optics.optics_manager.`**`OpticsManager`**(*yaml_dicts=None*, *cmds=None*, ***kwargs*)

Bases: `object`

The workhorse class for dealing with all externally defined Effect objects.

Parameters

yaml_dicts
[list of dict] The nested dicts describing the Effects from the relevant YAML files, which include `effects` and `properties` sub-dictionaries

kwargs
[expanded dict] Any extra information not directly related to the optical elements

`add_effect`(*effect*, *ext=0*)

Add an Effect object to an OpticalElement at index `ext`.

Parameters

effect
[Effect] Effect object to be added

ext
[int] Index number of the desired OpticalElement, contained in the list `self.optical_elements`

property all_effects

Get all effects in all optical elements.

property area

property detector_array_effects

Get effects with z_order = 900…999.

property detector_effects

Get effects with z_order = 800…899.

property detector_setup_effects

Get effects with z_order = 400…499 (DetectorLists only!).

property display_name

property fov_effects

Get effects with z_order = 600…699.

property fov_setup_effects

Get effects with z_order = 200…299.

get_all(*class_type*)

Return list of all effects from all optical elements with *class_type*.

Parameters

class_type
[class object] The class to be searched for. Must be an class object with base-class `Effect`

Returns

effects
[list of Effect objects]

get_z_order_effects(*z_level: int*)

Return a list of all effects with a z_order keywords within *z_level*.

Effect z_order values are classified according to the following:

- Make a FOV list - z_order = 0..99
- Make a image plane - z_order = 100..199
- Apply Source altering effects - z_order = 200..299
- Apply FOV specific (3D) effects - z_order = 300..399
- Apply FOV-independent (2D) effects - z_order = 400..499
- Apply XXX effects - z_order = 500..599
- Apply XXX effects - z_order = 600..699
- Apply lambda-independent 2D image plane effects - z_order = 700..799
- Apply detector effects - z_order = 800..899
- Apply detector array effects - z_order = 900..999

Parameters

z_level
[{0, 100, 200, 300, 400, 500, 600, 700, 800, 900}] 100-range of z_orders.

Returns

effects
[list of Effect objects]

property image_plane_effects

Get effects with z_order = 700…799.

property image_plane_headers

Get headers from detector setup effects.

property image_plane_setup_effects

Get effects with z_order = 300…399.

property is_spectroscope

Return True if any of the effects is a spectroscope.

list_effects()

load_effects(*yaml_dicts*, ***kwargs*)

Generate an OpticalElement for each section of the Optical System.

Make an `OpticalElement` for each YAML document in the system. For example there should be a YAML document for each of the following:

- Atmosphere
- Telescope
- Relay optics
- Instrument
- Detector

The YAML files can each be separate `.yaml` files, or be contained in a single `.yaml` file separated by a yaml-document-separator: ``

— ``.

Parameters

yaml_dicts
[list of dicts] Each YAML dict should contain the descriptions of the Effects needed by each `OpticalElement`.

pretty_str() → str

Return formatted string representation as str.

report(*filename=None*, *output='rst'*, *rst_title_chars='_^#*+'*, ***kwargs*)

set_derived_parameters()

property source_effects

Get effects with z_order = 500…599.

property surfaces_table

Get combined surface table from effects with z_order = 100…199.

property system_transmission

update(**obs_dict*)

Update the meta dictionary with keyword-value pairs.

Parameters

obs_dict
[expanded dict] Keyword-Value pairs to be added to self.meta

write_string(*stream: TextIO*) → None

Write formatted string representation to I/O stream

scopesim.optics.radiometry_utils module

scopesim.optics.radiometry_utils.**add_surface_to_table**(*tbl*, *surf*, *name*, *position*, *silent=True*)

scopesim.optics.radiometry_utils.**combine_emissions**(*tbl*, *surfaces*, *row_indexes*, *etendue*, *use_area=False*)

Combine thermal emission from a series of surfaces.

The function traces thermal emission through an optical system, taking into account the finite reflectivities/transmissivities and emissivities of the surfaces. The function assumes that etendue is conserved through the system, i.e. surfaces are neither over- nor undersized.

Parameters

tbl
[astropy Table] Required columns are *name* and *action* (reflection or transmission)

surfaces: OrderedDict of SpectralSurface
Keys are the names from tbl, values are of type *SpectralSurface*

row_indexes
[list of int] Rows of tbl (i.e. surfaces) to combine

etendue, use_area
[not needed (TODO: remove)]

Returns

SourceSpectrum

scopesim.optics.radiometry_utils.**combine_tables**(*new_tables*, *old_table=None*, *prepend=False*)

scopesim.optics.radiometry_utils.**combine_throughputs**(*tbl*, *surfaces*, *rows_indexes*)

scopesim.optics.radiometry_utils.**string_to_table**(*tbl*)

scopesim.optics.spectrograph module

scopesim.optics.surface module

class scopesim.optics.surface.**PoorMansSurface**(*emission: Any*, *throughput: Any*, *meta: Any*)

Bases: object

Solely used by SurfaceList.

emission: Any

meta: Any

throughput: Any

class scopesim.optics.surface.**SpectralSurface**(*filename=None*, *cmds=None*, ***kwargs*)

Bases: object

Initialised by a file containing one or more of the following columns.

transmission, emissivity, reflection. The column wavelength must be given. Alternatively kwargs for the above mentioned quantities can be passed as arrays. If they are not Quantities, then a unit should also be passed with the <array_name>_unit syntax (i.e. emission_unit or wavelength_unit)

If temperature is not given as a Quantity, it defaults to degrees Celsius.

property area

property emission

Look for an emission array in self.meta.

If it doesn't find this, it defaults to creating a blackbody and multiplies this by the emissivity. Assumption is that `self.meta["temperature"]` is in `deg_C`, unless it is a `u.Quantity` with temperature unit attached. Return units are in `PHOTLAM arcsec^-2`, even though `arcsec^-2` is not given.

property emissivity

from_meta(*key*, *default_unit=None*)

Convert a specific value in the meta dict to a `Quantity`.

Parameters

key
[str] Which key to pull from self.meta

default_unit
[str, Unit] In case self.meta doesn't contain a unit for the desired key

Returns

meta_quantity
[Quantity]

property mirror_angle

property reflection

property throughput

property transmission

property wavelength

scopesim.optics.surface_utils module

scopesim.optics.surface_utils.**extract_base_from_unit**(*unit*, *base_unit*)

Extract `astropy` base unit from a compound unit.

Parameters

unit
[astropy.Unit]

base_unit
[Unit, str]

Returns

new_unit
[Unit] The input unit minus any base units corresponding to *base_unit*.

extracted_units
[Unit] Any base units corresponding to *base_unit*.

scopesim.optics.surface_utils.**extract_type_from_unit**(*unit*, *unit_type*)

Extract `astropy` physical type from a compound unit.

Parameters

unit
[astropy.Unit]

unit_type
[str] The physical type of the unit as given by `astropy`

Returns

new_unit
[Unit] The input unit minus any base units corresponding to *unit_type*.

extracted_units
[Unit] Any base units corresponding to *unit_type*.

scopesim.optics.surface_utils.**make_emission_from_array**(*flux*, *wave*, *meta*) → SourceSpectrum

Create an emission SourceSpectrum using an array.

Takes care of bins and solid angles. The solid_angle is kept in the returned SourceSpectrum meta dictionary under self.meta[“solid_angle”].

Parameters

flux
[array-like, Quantity] if flux is not an array, the `emission_unit` must be in meta dict

wave
[array-like, Quantity] if flux is not an array, the `wavelength_unit` must be in meta dict

meta
[dict]

Returns

flux
[synphot.SourceSpectrum]

scopesim.optics.surface_utils.**make_emission_from_emissivity**(*temp: Quantity*, *emiss_src_spec*) → SourceSpectrum

Create an emission SourceSpectrum using blackbody and emissivity curves.

Parameters

temp
[Quantity[Kelvin]] Blackbody temperature.

emiss_src_spec
[synphot.SpectralElement] An emissivity response curve in the range [0..1]

Returns

flux
[synphot.SourceSpectrum]

scopesim.optics.surface_utils.**normalise_flux_if_binned**(*flux*, *wave*)

Convert a binned flux Quantity array back into flux density.

The flux density normalising unit is taken from the wavelength Quantity unit.

Parameters

flux
[array-like Quantity] flux unit must include `bin`, e.g. `ph s-1 m-2 bin-1`

wave
[array-like Quantity]

Returns

flux
[array-like Quantity]

Module contents

scopesim.reports package

Submodules

scopesim.reports.report_generator module

class scopesim.reports.report_generator.**ReportGenerator**(*pkg_name*)

Bases: `object`

rst_default_yaml()

scopesim.reports.rst_utils module

scopesim.reports.rst_utils.**latexify_rst_text**(*rst_text*, *filename=None*, *path=None*, *title_char='='*, *float_figures=True*, *use_code_box=True*)

Converts an RST string (block of text) into a LaTeX string

NOTE: plots will NOT be generated with this command. For that we must invoke the `plotfiy` command.

Parameters

rst_text
[str]

filename
[str, optional] What to name the latex file. If None, the filename is derived from the text title

path
[str, optional] Where to save the latex file

title_char
[str, optional] The character used to underline the rst text title. Usually "=".

float_figures
[bool, optional] Set to False if figures should not be placed by LaTeX. Replaces all `egin{figure}` with `egin{figure}[H]`

use_code_box
[bool, optional] Adds a box around quote blocks

Returns

tex_str
[str] The same string or block of text in LaTeX format

Examples

::

rst_text = '' Meaning of life ===============

Apparently it's 42. Lets plot

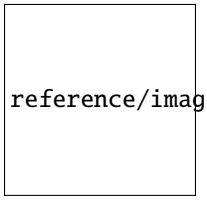

Fig. 1: This is an included figure caption

''

plotify_rst_text(rst_text) latexify_rst_text(rst_text, filename="my_latex_file", path="./")

scopesim.reports.rst_utils.**plotify_rst_text**(*rst_text*)

Generates and saves plots from code blocks in an RST string

The save directory for the plots defaults to `scopesim.rc.__config__["!SIM.reports.image_path"]`. This can be overridden ONLY inside a COMMENT block using the path keyword.

Parameters

rst_text
[str] Any RST text string

Notes

- Possible actions are: [reset, clear-figure, plot]
- Code is retained between code blocks in the same string, so we do not need to re-write large sections of code
- By default `import numpy as np` and `import matplotlib.pyplot as plt` are loaded automatically, so these do not need to be explicitly specified in each code block.
- THE EXCEPTION is when the action `reset` is specified. This clears the code_context variable.

Examples

The following rst text will generate a plot and save it in three formats:

```
..
```

!! processed by numpydoc !!

`scopesim.reports.rst_utils.`**`process_code`**(*context_code*, *code*, *options*)

Extracts and adds code from the node text to the context_code string

Code can be passed in either a `literal_block` or `comment` docutils node. The options regarding what to do with the code are included in either the :class: and :name: tag of a `literal_block` node, or in a yaml header section in a `comment` node.

See below for examples of code blocks.

Options for controlling what happens to the code block are as follows:

- name: The filename for the plot
- **format: Any matplotlib-accepted file format, e.g: png, pdf, svg, etc.**
  Multiple file formats can be
- **action: [reset, clear-figure, plot]**
  - `reset` clears the context_code string. By default code is saved from previous code blocks.
  - `clear-figure` adds `plt.clf()` to the context string before the current code block is added
  - `plot` adds `plt.savefig({name}.{format})` to the context string. If multiple formats are given, these will be iterated over.

For `comment` blocks, options should be given in a yaml style header, separated form the code block by exactly three (3) hyphens ('—')

For `literal_block` blocks, we hijack the `:class:` and `:name:` attributes. See the examples below. All action keywords are passed to `:class:`. Format keys are passed as `format-<key>`.

Parameters

context_code
[str] code from previous Nodes

code
[str] code from the current Node

options
[dict] options dictionary derived from Node attributes or RST header blocks

Returns

context_code
[str]

Examples

Example of `literal_block` code block:

```
.. code::
    :name: my_fug
    :class: reset, clear-figure, plot, format-png

    plt.plot([0,1], [1,1])

.. figure:: my_fug.png
    :name: fig:my_fug
```

Example of a `comment` code block:

```
..
    name: my_fug2
    format: [jpg, svg]
    action: [reset, clear-figure, plot]
    ---
    plt.plot([0,1], [1,0])

.. figure:: my_fug2.jpg
    :name: fig:my_fug2
```

scopesim.reports.rst_utils.**process_comment_code**(*node*, *context_code*)
Add code from a `comment` node to the context_code string

scopesim.reports.rst_utils.**process_literal_code**(*node*, *context_code*)
Add code from a `literal_block` node to the context_code string

scopesim.reports.rst_utils.**rstify_rst_text**(*rst_text*, *filename=None*, *path=None*, *title_char='='*)
The same as `latexify_rst_text`, but the output is in RST format

scopesim.reports.rst_utils.**table_to_rst**(*tbl*, *indent=0*, *rounding=None*)

scopesim.reports.rst_utils.**walk**(*node*, *context_code=None*)
Recursively walk through a docutils doctree and run/plot code blocks

Parameters

node
[docutils.node.Node]

context_code
[str, optional] A code string inherited from previous code/comment nodes

Returns

context_code
[str] Code to be inherited by subsequent code/comment nodes

Module contents

scopesim.server package

Submodules

scopesim.server.database module

Functions to download instrument packages and example data.

exception scopesim.server.database.**PkgNotFoundError**

Bases: Exception

Unable to find given package or given release of that package.

scopesim.server.database.**crawl_server_dirs**(*client=None*) → Iterator[tuple[str, set[str]]]

Search all folders on server for .zip files.

scopesim.server.database.**download_package**(*pkg_path*, *save_dir=None*, *url=None*, *from_cache=None*)

DEPRECATED – only kept for backwards compatibility

Downloads a package to the local disk

Parameters

pkg_path
[str, list] A `.zip` package path as given by `list_packages()`

save_dir
[str] The place on the local disk where the `.zip` package is to be saved. If left as None, defaults to the value in scopesim.rc.__config__["!SIM.file.local_packages_path"]

url
[str] The URL of the IRDB HTTP server. If left as None, defaults to the value in scopesim.rc.__config__["!SIM.file.server_base_url"]

from_cache
[bool] Use the cached versions of the packages. If None, defaults to the RC value: `!SIM.file.use_cached_downloads`

Returns

save_path
[str] The absolute path to the saved `.zip` package

scopesim.server.database.**download_packages**(*pkg_names: Union[Iterable[str], str]*, *release: str = 'stable'*, *save_dir: Optional[str] = None*) → list[pathlib.Path]

Download one or more packages to the local disk.

1. Download stable, dev
2. Download specific version
3. Download from github via url

Parameters

pkg_names
[str, list] A list of package names, see `list_packages()`

release
[str, optional] By default, the most recent stable version of a package is downloaded. Other options are: - "stable" : the most recent stable version - "latest" : the latest development version to be published - a specific package filename as given by list_packages (see examples) - a github url for the specific branch and package (see examples)

save_dir
[str, optional] The place on the local disk where the `.zip` package is to be saved. If left as None, defaults to the value in scopesim.rc.__config__["!SIM.file.local_packages_path"]

from_cache
[bool, optional] Use the cached versions of the packages. If None, defaults to the RC value: `!SIM.file.use_cached_downloads`

Returns

save_path
[str] The absolute path to the saved `.zip` package

Examples

::

from scopesim import download_packages, list_packages

Stable release of a list of packages download_packages(["test_package", "test_package"])

Development release of a single package download_packages("test_package", release="latest")

Specific version of the package list_packages("test_package") download_packages("test_package", release="2022-04-09.dev")

Specific package from a Gtihub commit hash or branch/tag name (use "@" or ":") download_packages("ELT", release="github:728761fc76adb548696205139e4e9a4260401dfc") download_packages("ELT", release="github@728761fc76adb548696205139e4e9a4260401dfc") download_packages("ELT", release="github@dev_master")

`scopesim.server.database.`**`get_all_latest`**(*version_groups: Mapping[str, Iterable[str]]*) → Iterator[tuple[str, str]]

Yield the most recent stable (not "dev") version of each package.

Parameters

version_groups
[Mapping[str, Iterable[str]]] DESCRIPTION.

Yields

Iterator[tuple[str, str]]
Iterator of package name - latest version pairs.

`scopesim.server.database.`**`get_all_package_versions`**(*client=None*) → dict[str, list[str]]

Gather all versions for all packages present in any folder on server.

scopesim.server.database.**get_all_packages_on_server**() → Iterator[tuple[str, set]]

Retrieve all unique package names present on server in known folders.

Currently hardcoded to look in folders "locations", "telescopes" and "instruments". Any packages not in these folders are not returned.

This generator function yields key-value pairs, containing the folder name as the key and the set of unique package names in value. Recommended useage is to turn the generator into a dictionary, i.e.:

::

package_dict = dict(get_all_packages_on_server())

Yields

Iterator[tuple[str, set]]
Key-value pairs of folder and corresponding package names.

scopesim.server.database.**get_all_stable**(*version_groups: Mapping[str, Iterable[str]]*) → Iterator[tuple[str, str]]

Yield the most recent version (stable or dev) of each package.

Parameters

version_groups
[Mapping[str, Iterable[str]]] DESCRIPTION.

Yields

Iterator[tuple[str, str]]
Iterator of package name - latest stable version pairs.

scopesim.server.database.**get_base_url**()

Get instrument package server URL from rc.__config__.

scopesim.server.database.**get_latest**(*versions: Iterable[str]*) → str

Return the most recent version (stable or dev).

scopesim.server.database.**get_package_folders**(*client*) → dict[str, str]

Map package names to server locations.

scopesim.server.database.**get_server_folder_package_names**(*client*, *dir_name: str*) → set[str]

Retrieve all unique package names present on server in *dir_name* folder.

Parameters

client
[httpx.Client] Pre-existing httpx Client context manager.

dir_name
[str] Name of the folder on the server.

Returns

package_names
[set of str] Set of unique package names in *dir_name* folder.

Raises

ValueError
Raised if no valid packages are found in the given folder.

scopesim.server.database.**get_server_package_list**()

scopesim.server.database.**get_stable**(*versions: Iterable[str]*) → str

Return the most recent stable (not "dev") version.

scopesim.server.database.**group_package_versions**(*all_packages: Iterable[tuple[str, str]]*) → Iterator[tuple[str, list[str]]]

Group different versions of packages by package name.

scopesim.server.database.**list_packages**(*pkg_name: Optional[str] = None*) → list[str]

List all packages, or all variants of a single package.

Parameters

pkg_name
[str, optional]

- None: lists all stable packages on the server
- <PackageName>: lists all variants of <PackageName> on the server

Returns

pkg_names
[list]

Examples

::

from scopesim import list_packages

list all stable packages on the server list_packages()

list all variants of a specific package list_packages("Armazones")

scopesim.server.download_utils module

Used only by the *database* and *github_utils* submodules.

exception scopesim.server.download_utils.**ServerError**

Bases: Exception

Some error with the server or connection to the server.

scopesim.server.download_utils.**create_client**(*base_url*, *cached: bool = False*, *cache_name: str = ''*)

Create httpx Client instance, should support cache at some point.

scopesim.server.download_utils.**get_server_folder_contents**(*client*, *dir_name: str*, *unique_str: str = '.zip$'*) → Iterator[str]

Find all zip files in a given server folder.

scopesim.server.download_utils.**handle_download**(*client*, *pkg_url: str*, *save_path: Path*, *pkg_name: str*, *padlen: int*, *chunk_size: int = 128*, *disable_bar=False*) → None

Perform a streamed download and write the content to disk.

scopesim.server.download_utils.**handle_unzipping**(*save_path: Path*, *save_dir: Path*, *pkg_name: str*, *padlen: int*) → None

Unpack a zipped folder, usually called right after downloading.

scopesim.server.download_utils.**send_get**(*client*, *sub_url*, *stream: bool = False*)

Send a GET request (streamed or not) using an existing client.

The point of this function is mostly elaborate exception handling.

scopesim.server.example_data_utils module

Store the example data functions here instead of polluting database.py.

scopesim.server.example_data_utils.**download_example_data**(*file_path: Union[Iterable[str], str]*, *save_dir: Optional[Union[Path, str]] = None*, *url: Optional[str] = None*, *from_cache: Optional[bool] = None*) → list[pathlib.Path]

Download example fits files to the local disk.

Parameters

file_path
[str, list] Name(s) of FITS file(s) as given by `list_example_data()`

save_dir
[str] The place on the local disk where the downloaded files are to be saved. If left as None, defaults to the current working directory.

url
[str] The URL of the database HTTP server. If left as None, defaults to the value in scopesim.rc.__config__["!SIM.file.server_base_url"]

from_cache
[bool] Use the cached versions of the files. If None, defaults to the RC value: `!SIM.file.use_cached_downloads`

Returns

save_path
[Path or list of Paths] The absolute path(s) to the saved files

scopesim.server.example_data_utils.**get_server_elements**(*url: str*, *unique_str: str = '/'*) → list[str]

Return a list of file and/or directory paths on the HTTP server `url`.

Parameters

url
[str] The URL of the IRDB HTTP server.

unique_str
[str, list] A unique string to look for in the beautiful HTML soup: "/" for directories this, ".zip" for packages

Returns

paths
[list] List of paths containing in `url` which contain `unique_str`

scopesim.server.example_data_utils.**list_example_data**(*url: Optional[str] = None*, *return_files: bool = False*, *silent: bool = False*) → list[str]

List all example files found under `url`.

Parameters

url
[str] The URL of the database HTTP server. If left as None, defaults to the value in scopesim.rc.__config__["!SIM.file.server_base_url"]

return_files
[bool] If True, returns a list of file names

silent
[bool] If True, does not print the list of file names

Returns

all_files
[list of str] A list of paths to the example files relative to `url`. The full string should be passed to `download_example_data`.

scopesim.server.github_utils module

Used only by the *database* submodule.

Original comment for these functions:
2022-04-10 (KL) Code taken directly from https://github.com/sdushantha/gitdir Adapted for ScopeSim usage. Many thanks to the authors!

scopesim.server.github_utils.**create_github_url**(*url: str*) → None

From the given url, produce a URL compatible with Github's REST API.

Can handle blob or tree paths.

scopesim.server.github_utils.**download_github_folder**(*repo_url: str*, *output_dir: Union[Path, str] = './'*) → None

Download the files and directories in repo_url.

Re-written based on the on the download function here

Module contents

scopesim.source package

Submodules

scopesim.source.source module

old functionality to implement: # - provide x, y, lam, spectra, weight, ref # - overridden + : number, Source, SourceSpectrum # - overridden * : number, SpectralElement # - write to and read from file # - shift all fields # - rotate around the centre # - photons_in_range returns the photons per spectrum in a wavelength range # - image_in_range returns an image of the source for a wavelength range # # old functionality which will be removed: # - project_onto_chip # - apply_optical_train # # old structure –> new structure: # - all data held in 6 arrays # –> new dicts for fields, spectrum # field can be a Table or an ImageHDU # spectrum is a SourceSpectrum # # Use cases: # image + spectrum # images + spectra # table + spectrum # table + spectra # # table columns = x, y, spec_id, weight # table meta keywords = x_unit,

y_unit # # image header keywords = WCS, SPEC_ID, WEIGHT # [WCS = CRPIXn, CRVALn = (0,0), CTYPEn, CDn_m, NAXISn, CUNITn

class scopesim.source.source.**Source**(*filename=None*, *cube=None*, *ext=0*, *lam=None*, *spectra=None*, *x=None*, *y=None*, *ref=None*, *weight=None*, *table=None*, *image_hdu=None*, *flux=None*, ***kwargs*)

Bases: *SourceBase*

Create a source object from a file or from arrays

A Source object must consist of a spatial and a spectral description of the on-sky source. Many sources can be added together and kept in memory as a single Source object.

The spatial descriptions are kept in the `<Source>.fields` list, while the spectral descriptions are in the `<Source>.spectra` list.

The spatial description can be built from any combination of:

- a list of arrays (like in SimCADO >v0.5)
- astropy Table objects
- astropy ImageHDU objects
- on disk FITS files
- on disk ASCII tables

The spectral descriptions can be passed as either `synphot.SourceSpectrum` objects, or a set of two equal length arrays for wavelength and flux.

Hint: Initialisation parameter combinations include:

New ScopeSim-style input - `table=<astropy.Table>, spectra=<list of synphot.SourceSpectrum>` - `table=<astropy.Table>, lam=<array>, spectra=<list of array>` - `image_hdu=<fits.ImageHDU>, spectra=<list of synphot.SourceSpectrum>` - `image_hdu=<fits.ImageHDU>, lam=<array>, spectra=<list of array>` - `image_hdu=<fits.ImageHDU>, flux=<astropy.Quantity>`

Old SimCADO-style input - `x=<array>, y=<array>, ref=<array>, spectra=<list of synphot.SourceSpectrum>` - `x=<array>, y=<array>, ref=<array>, spectra=<list of array>, lam=<array>` - `x=<array>, y=<array>, ref=<array>, weight=<array>, spectra=<list of array>, lam=<array>`

More details on the content of these combinations can be found in the use-case documentation.

Parameters

filename
[str]

lam
[np.array] [um] Wavelength bins of length (m)

spectra
[list of synphot.SourceSpectra] [ph/s/cm2/AA]

x, y
[np.array] [arcsec] coordinates of where the emitting files are relative to the centre of the field of view

ref
[np.array] the index for .spectra which connects a position (x, y) to a spectrum `flux(x[i], y[i]) = spectra[ref[i]] * weight[i]`

weight
[np.array] A weighting to scale the relevant spectrum for each position

table
[astropy.Table]

image_hdu
[fits.ImageHDU] [arcsec-2] The .data array is simply a map of weights for the assiciated spectrum referenced by .header[“SPEC_REF]. Surface brightness values are assumed to be per arcsec2

flux
[astropy.Quantity] [u.mag, u.ABmag, u.Jy] Flux values are converted to a reference spectrum that is referenced by image_hdu.header[“SPEC_REF”]. flux can only be used in conjuction with image_hdu

See also:

`synphot`
`https://synphot.readthedocs.io/en/latest/`

Attributes

fields
[list] The spatial distribution of the on-sky source, either as `fits.ImageHDU` or `astropy.Table` objects

spectra
[list of `synphot.SourceSpectrum` objects] List of spectra associated with the fields

meta
[dict] Dictionary of extra information about the source

`add_bandpass`(*bandpass*)

`append`(*source_to_add*)

`property cube_fields`
List of fields that are defined through three-dimensional cubes

`dump`(*filename*)
Save to filename as a pickle

`fluxes`(*wave_min*, *wave_max*, ***kwargs*)

`image`(*wave_min*, *wave_max*, ***kwargs*)

`property image_fields`
List of fields that are defined through two-dimensional images

`image_in_range`(*wave_min*, *wave_max*, *pixel_scale=<Quantity 1. arcsec>*, *layers=None*, *area=None*, *spline_order=1*, *sub_pixel=False*)

`classmethod load`(*filename*)
Load :class:’.Source’ object from filename

make_copy()

photons_in_range(*wave_min*, *wave_max*, *area=None*, *indexes=None*)

Parameters

wave_min
[float, u.Quantity] [um]

wave_max
[float, u.Quantity] [um]

area
[float, u.Quantity, optional] [m2]

indexes
[list of integers, optional]

Returns

counts
[u.Quantity list] [ph / s / m2] if area is None [ph / s] if area is passed

plot()

Plot the location of source components

Source components instantiated from 2d or 3d ImageHDUs are represented by their spatial footprint. Source components instantiated from tables are shown as points.

rotate(*angle*, *offset=None*, *layers=None*)

shift(*dx=0*, *dy=0*, *layers=None*)

Shifts the position of one or more fields w.r.t. the optical axis

Parameters

dx, dy
[float] [arcsec]

layers
[list of ints] which .fields entries to shift

property table_fields

List of fields that are defined through tables

scopesim.source.source_templates module

scopesim.source.source_templates.**ab_spectrum**(*mag=0*)

scopesim.source.source_templates.**empty_sky**(*flux=0*)

Returns an empty source so that instrumental fluxes can be simulated

Returns

sky
[Source]

scopesim.source.source_templates.**st_spectrum**(*mag=0*)

scopesim.source.source_templates.**star**(*x=0*, *y=0*, *flux=0*)

Source object for a single star in either vega, AB magnitudes, or Jansky

The star is associated with the reference spectrum for each photometric system, therefore a reference wavelength or filter does not need to be given

Parameters

x, y
[float] [arcsec] position from centre of field of view

flux
[float] [vega mag, AB mag, Jy] Stellar brightness

Returns

src
[Source] A source object with a single entry table field and a reference spectrum

scopesim.source.source_templates.**star_field**(*n*, *mmin*, *mmax*, *width*, *height=None*, *use_grid=False*)

Creates a super basic field of stars with random positions and brightnesses

Parameters

n
[int] number of stars

mmin, mmax
[float, astropy.Quantity] [mag, ABmag, Jy] min and max magnitudes/fluxes of the population stars. If floats, then assumed Quantity is vega magnitudes

width
[float] [arcsec] width of region to put stars in

height
[float, optional] [arcsec] if None, then height=width

use_grid
[bool, optional] Place stars randomly or on a grid

Returns

stars
[scopesim.Source object] A Source object with a field of stars that can be fed into the method: OpticalTrain.observe()

See also:

`OpticalTrain.observe`
`OpticalTrain.readout`

scopesim.source.source_templates.**uniform_illumination**(*xs*, *ys*, *pixel_scale*, *flux=None*, *spectrum=None*)

Return a Source for a uniformly illuminated area

Parameters

xs, ys
[list of float] [arcsec] min and max extent of each dimension relative to FOV centre E.g. *xs=[-1, 1], ys=[5, 5.5]*

pixel_scale
[float] [arcsec]

flux
[astropy.Quantity] [mag, ABMag, Jy] Flux per arcsecond of the Source

Returns

src
[scopesim.Source]

Examples

A 200x200 uniform illumination Source at 1 Jy/arcsec2

```
src = uniform_illumination(xs=[-1,1], ys=[-1, 1],
                           pixel_scale=0.01, flux=1*u.Jy)
```

A source that extends just past the MICADO 15" slit dimensions with a flux of 10 mag/arcsec2

```
src = uniform_illumination(xs=[-8, 8], ys=[-0.03, 0.03],
                           pixel_scale=0.004, flux=10*u.mag)
```

Using a self made frequency-comb spectrum with 1 Jy lines ever 0.1µm

```
import numpy as np
from astropy import units as u
from synphot import SourceSpectrum, Empirical1D

wave = np.arange(0.7, 2.5, 0.001) * u.um
flux = np.zeros(len(wave))
flux[::100] = 1 * u.Jy
spec = SourceSpectrum(Empirical1D, points=wave, lookup_table=flux)

src = uniform_illumination(xs=[-8, 8], ys=[-0.03, 0.03],
                           pixel_scale=0.004, spectrum=spec)
```

scopesim.source.source_templates.**uniform_source**(*sp=None*, *extent=60*)

Simplified form of scopesim_templates.misc.uniform_source, mostly intended for testing

This function creates an image with extend^2 pixels with pixel size of 1 arcsec^2 so provided amplitudes are in flux or magnitudes per arcsec^2

It accepts any synphot.SourceSpectrum compatible object

sp
[synphot.SourceSpectrum] defaults to vega_spectrum() with magnitude 0 mag/arcsec2

extent
[int, default 60] extension of the field in arcsec, will always produce a square field. Default value produces a field of 60x60 arcsec

scopesim.source.source_templates.**vega_spectrum**(*mag=0*)

scopesim.source.source_utils module

scopesim.source.source_utils.**convert_to_list_of_spectra**(*spectra*, *lam*)

scopesim.source.source_utils.**make_img_wcs_header**(*pixel_scale*, *image_size*)

Create a WCS header for an image

pixel_scale
[float] arcsecs

image_size
[tuple] x, y where x, y are integers

scopesim.source.source_utils.**photons_in_range**(*spectra*, *wave_min*, *wave_max*, *area=None*, *bandpass=None*)

Parameters

spectra
wave_min
[um]

wave_max
[um]

area
[Quantity] [m2]

bandpass
[SpectralElement]

Returns

counts
[u.Quantity array]

scopesim.source.source_utils.**scale_imagehdu**(*imagehdu*, *waverange*, *area=None*)

scopesim.source.source_utils.**validate_source_input**(***kwargs*)

Module contents

9.1.2 Submodules

scopesim.base_classes module

class scopesim.base_classes.**DetectorBase**

Bases: object

class scopesim.base_classes.**FOVSetupBase**

Bases: object

class scopesim.base_classes.**FieldOfViewBase**

Bases: object

class scopesim.base_classes.**ImagePlaneBase**

Bases: object

class scopesim.base_classes.**PoorMansHeader**(*dic=None*)

Bases: object

as_header()

items()

keys()

update(*obj*)

values()

Like dict.values().

class scopesim.base_classes.**SourceBase**

Bases: object

scopesim.rc module

Global configurations for ScopeSim.

scopesim.utils module

Helper functions for ScopeSim.

scopesim.utils.**airmass2zendist**(*airmass*)

Convert airmass to zenith distance.

Parameters

airmass
[float (>= 1)]

Returns

zenith distance in degrees

scopesim.utils.**airmass_to_zenith_dist**(*airmass*)

Return zenith distance in degrees.

Z = arccos(1/X)

scopesim.utils.**bug_report**() → None

Print versions of dependencies for inclusion in bug report.

scopesim.utils.**bug_report_to_file**(*filename*) → None

Like bug_report, but writes to file instead of printing.

scopesim.utils.**change_table_entry**(*tbl*, *col_name*, *new_val*, *old_val=None*, *position=None*)

scopesim.utils.**check_keys**(*input_dict: Union[Mapping, Iterable]*, *required_keys: Set*, *action: str = 'error'*, *all_any: str = 'all'*) → bool

Check to see if all/any of the required keys are present in a dict.

Changed in version v0.8.0: The *required_keys* parameter should now be a set.

Parameters

input_dict
[Union[Mapping, Iterable]] The mapping to be checked.

required_keys
[Set] Set containing the keys to look for.

action
[{"error", "warn", "warning"}, optional] What to do in case the check does not pass. The default is "error".

all_any
[{"all", "any"}, optional] Whether to check if "all" or "any" of the *required_keys* are present. The default is "all".

Returns

keys_present
[bool] `True` if check succeded, `False` otherwise.

Raises

ValueError
Raised when an invalid parameter was passed or when *action* was set to "error" (the default) and the *required_keys* were not found.

`scopesim.utils.close_loop(*close_loop(zip(x, y))*)`

`scopesim.utils.convert_table_comments_to_dict(*tbl*)`

`scopesim.utils.deriv_polynomial2d(*poly*)`
Derive (gradient) of a Polynomial2D model.

Parameters

poly
[astropy.modeling.models.Polynomial2D]

Returns

gradient
[tuple of Polynomial2d]

`scopesim.utils.figure_factory(*nrows=1*, *ncols=1*, ***kwargs*)`
Default way to init fig and ax, to easily modify later.

`scopesim.utils.figure_grid_factory(*nrows=1*, *ncols=1*, ***kwargs*)`
Gridspec variant.

`scopesim.utils.find_file(*filename*, *path=None*, *silent=False*)`
Find a file in search path.

Parameters

filename
[str] name of a file to look for

path
[list] list of directories to search (default: ['./'])

silent
[bool] if True, remain silent when file is not found

Returns

Absolute path of the file

scopesim.utils.**from_currsys**(*item*, *cmds=None*)

Return the current value of a bang-string from `rc.__currsys__`.

scopesim.utils.**from_rc_config**(*item*)

scopesim.utils.**get_fits_type**(*filename*)

scopesim.utils.**get_meta_quantity**(*meta_dict*, *name*, *fallback_unit=''*)

Extract a Quantity from a dictionary.

Parameters

meta_dict
[dict]

name
[str]

fallback_unit
[Quantity]

Returns

quant
[Quantity]

scopesim.utils.**has_needed_keywords**(*header*, *suffix=''*)

Check to see if the WCS keywords are in the header.

scopesim.utils.**is_fits**(*filename*) → bool

scopesim.utils.**log_bug_report**(*level=10*) → None

Emit bug report as logging message.

scopesim.utils.**log_to_file**(*enable=True*)

Enable or disable logging to file (convenience function).

scopesim.utils.**nearest**(*arr*, *val*)

Return the index of the value from *arr* which is closest to *val*.

Parameters

arr
[np.ndarray, list, tuple] Array to be searched

val
[float, int] Value to find in *arr*

Returns

i
[int] index of array where the nearest value to *val* is

scopesim.utils.**parallactic_angle**(*ha*, *de*, *lat=-24.589167*)

Compute the parallactic angle.

Parameters

ha
[float] [hours] hour angle of target point

de
[float] [deg] declination of target point

lat
[float] [deg] latitude of observatory, defaults to Armazones

Returns

parang
[float] The parallactic angle

Notes

The parallactic angle is defined as the angle PTZ, where P is the .. math:: taneta = frac{cosphisin H}{sinphi cosdelta - cosphi sindelta cos H} It is negative (positive) if target point is east (west) of the meridian.

References

R. Ball: "A Treatise on Spherical Astronomy", Cambridge 1908

scopesim.utils.**power_vector**(*val*, *degree*)
Return the vector of powers of val up to a degree.

scopesim.utils.**pretty_print_dict**(*dic*, *indent=0*)

scopesim.utils.**quantify**(*item*, *unit*, *cmds=None*)
Ensure an item is a Quantity.

Parameters

item
[int, float, array, list, Quantity]

unit
[str, Unit]

Returns

quant
[Quantity]

scopesim.utils.**quantity_from_table**(*colname: str*, *table: Table*, *default_unit: str = ''*) → Quantity

scopesim.utils.**real_colname**(*name*, *colnames*, *silent=True*)

scopesim.utils.**return_latest_github_actions_jobs_status**(*owner_name='AstarVienna'*, *repo_name='ScopeSim'*, *branch='dev_master'*, *actions_yaml_name='tests.yml'*)
Get the status of the latest test run.

scopesim.utils.**set_console_log_level**(*level='INFO'*)
Set the level for the console handler (convenience function).

This controls what is actually printed to the console by ScopeSim. Accepted values are: DEBUG, INFO (default), WARNING, ERROR and CRITICAL.

scopesim.utils.**stringify_dict**(*dic*, *ignore_types=(<class 'str'>, <class 'int'>, <class 'float'>)*)
Turn a dict entries into strings for addition to FITS headers.

scopesim.utils.**top_level_catch**(*func*)

Catch any unhandled exceptions, log it including bug report.

scopesim.utils.**unit_from_table**(*colname: str*, *table: Table*, *default_unit: str = ''*) → Unit

Look for the unit for a column based on the meta dict keyword "<col>_unit".

scopesim.utils.**update_logging**(*capture_warnings=True*)

Reload logging configuration from `rc.__config__`.

scopesim.utils.**write_report**(*text*, *filename=None*, *output=None*)

Write a report string to file in latex or rst format.

scopesim.utils.**zendist2airmass**(*zendist*)

Convert zenith distance to airmass.

Parameters

zenith distance
[[deg]] Zenith distance angle

Returns

airmass in sec(z) approximation

scopesim.utils.**zenith_dist_to_airmass**(*zenith_dist*)

zenith_dist is in degrees.

X = sec(Z)

9.1.3 Module contents

Generalised telescope observation simulator.

CHAPTER

TEN

THE SCOPESIM PYTHON ECOSYSTEM

There are several packages in the ScopeSim ecosystem to be aware of:

- ScopeSim: The engine behind the whole simulator
- ScopeSim Templates: A series of helper function to generate on-sky targets
- SpeXtra: A pythonic interface to many common astronomical spectra libraries
- Pyckles: Pythonic access to the Pickles (1998) spectral library and Brown (2014) spectral library
- IRDB: The Instrument Reference Database, where the instrument packages are stored
- AnisoCADO: For making SCAO PSF cubes that readable by ScopeSim
- skycalc_ipy: Connects to ESOs SkyCalc server to get atmospheric spectra
- How Many Photons: A simple package for quickly calculating the number of photons within a given astronomical filter

Note: Much more information on these packages will be coming very soon!

CHAPTER

ELEVEN

CONTACT

- For bugs, please add an issue to the github repo
- For enquiries on implementing your own instrument package, please drop us a line at
  - astar.astro@univie.ac.at or
  - kieran.leschinski@univie.ac.at
- For friendly chat, join the slack at https://join.slack.com/t/scopesim/shared_invite/zt-143s42izo-LnyqoG7gH5j~aGn51Z~4IA

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