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# **sncosmo Documentation**

***Release 2.6.0***

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SNCosmo is a Python library for supernova cosmology analysis. It aims to make such analysis both as flexible and clear as possible.



## INSTALLATION

SNCosmo works on Python 3.4+ and depends on the following Python packages:

- [numpy](#)
- [scipy](#)
- [astropy](#)
- [extinction](#)

### 1.1 Install using conda (recommended)

If you are using Anaconda or the conda package manager, you can install SNCosmo from the conda-forge channel:

```
conda install -c conda-forge sncosmo
```

### 1.2 Install using pip

First ensure that numpy and cython are installed. Then:

```
pip install sncosmo
```

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**Note:** The `--no-deps` flag is optional, but highly recommended if you already have numpy, scipy and astropy installed, since otherwise pip will sometimes try to “help” you by upgrading your Numpy installation, which may not always be desired.

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**Note:** If you get a `PermissionError` this means that you do not have the required administrative access to install new packages to your Python installation. In this case you may consider using the `--user` option to install the package into your home directory. You can read more about how to do this in the [pip documentation](#).

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Do **not** install sncosmo or other third-party packages using `sudo` unless you are fully aware of the risks.

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**Note:** You will need a C compiler (e.g. `gcc` or `clang`) to be installed for the installation to succeed.

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## 1.3 Install latest development version

SNCosmo is being developed on [github](#). To get the latest development version using `git`:

```
git clone git://github.com/sncosmo/sncosmo.git
cd sncosmo
```

then:

```
pip install -e .
```

This will install a development version of the SNCosmo package that automatically picks up any changes that you made when you import `sncosmo` for the first time in a Python interpreter. If you make any edits to the Cython code in SNCosmo (files with `.c` or `.pyx` extensions), then you will need to run this command again to compile that code for your changes to be picked up.

## 1.4 Optional dependencies

Several additional packages are recommended for enabling optional functionality in SNCosmo.

- [matplotlib](#) for plotting functions.
- [iminuit](#) for light curve fitting using the Minuit minimizer in `sncosmo.fit_lc`.
- [emcee](#) for MCMC light curve parameter estimation in `sncosmo.mcmc_lc`.
- [nestle](#) for nested sampling light curve parameter estimation in `sncosmo.nest_lc`.

The [corner](#) package is also recommended for plotting results from the samplers `sncosmo.mcmc_lc` and `sncosmo.nest_lc`, but is not used by any part of `sncosmo`.



## SUPERNOVA MODELS

### 2.1 Getting Started

Create a model using the built-in “source” named 'hsiao':

```
>>> import sncosmo
>>> model = sncosmo.Model(source='hsiao')
```

Set the redshift, time-of-zero-phase and the amplitude:

```
>>> model.set(z=0.5, t0=55000., amplitude=1.e-10)
```

Generate synthetic photometry through an observer-frame bandpass:

```
>>> model.bandmag('desr', 'ab', [54990., 55000., 55020.])
array([ 24.82381795,  24.41496701,  25.2950865  ])
```

Equivalent values in photons / s / cm<sup>2</sup>:

```
>>> model.bandflux('desr', [54990., 55000., 55020.])
array([ 7.22413301e-05,  1.05275209e-04,  4.68034980e-05])
```

Equivalent values scaled so that 1 is equivalent to an AB magnitude of 25:

```
>>> model.bandflux('desr', [54990., 55000., 55020.], zp=25., zpsys='ab')
array([ 1.17617737,  1.71400939,  0.7620183  ])
```

Generate an observer-frame spectrum at a given time and wavelengths (in ergs/s/cm<sup>2</sup>/Angstrom):

```
>>> model.flux(54990., [4000., 4100., 4200.])
array([ 4.31210900e-20,  7.46619962e-20,  1.42182787e-19])
```

## 2.2 Creating a model using a built-in source

A Model in sncosmo consists of

- **One “source”** A model of the spectral evolution of the source (e.g., a supernova).
- **Zero or more “propagation effects”** Models of how intervening structures (e.g., host galaxy dust, milky way dust) affect the spectrum.

In the above example, we created a model with no propagation effects, using one of the built-in Source instances that sncosmo knows about: 'hsiao'. See the full [List of Built-in Sources](#) that sncosmo knows about.

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**Note:** In fact, the data for “built-in” sources are hosted remotely, downloaded as needed, and cached locally. So the first time you load a given model, you need to be connected to the internet. You will see a progress bar as the data are downloaded. By default, SNCosmo will use a subdirectory of the AstroPy cache directory for this purpose, e.g., `$HOME/.astropy/cache/sncosmo`, but this can be changed by setting the `data_dir` configuration parameter in `$HOME/.astropy/config/sncosmo.cfg`. See [Directory Configuration](#) for more information.

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Some built-in source models have multiple versions, which can be explicitly retrieved using the [get\\_source](#) function:

```
>>> source = sncosmo.get_source('hsiao', version='2.0')
>>> model = sncosmo.Model(source=source)
```

## 2.3 Model parameters

Each model has a set of parameter names and values:

```
>>> model.param_names
['z', 't0', 'amplitude']
>>> model.parameters
array([ 0.,  0.,  1.])
```

These can also be retrieved as:

```
>>> model.get('z')
0.0
>>> model['z']
0.0
```

Parameter values can be set by any of the following methods:

```
>>> model.parameters[0] = 0.5
>>> model.parameters = [0.5, 0., 1.] # set the entire array
>>> model['z'] = 0.5
>>> model.set(z=0.5)
>>> model.set(z=0.5, amplitude=2.0) # Can specify multiple parameters
>>> model.update({'z': 0.5, 'amplitude': 2.0})
```

What do these parameters mean? The first two, `z` and `t0` are common to all [Model](#) instances:

- `z` is the redshift of the source.
- `t0` is the observer-frame time corresponding to the source’s phase=0.

Note that in some sources  $\text{phase}=0$  might be at explosion while others might be at max: the definition of phase is arbitrary. However, observed time is always related to phase via  $\text{time} = t_0 + \text{phase} * (1 + z)$

The next, `amplitude`, is specific to the particular type of source. In this case, the source is a simple spectral timeseries that can only be scaled up and down. Other sources could have other parameters that affect the shape of the spectrum at each phase.

For a given model, you can set the `amplitude` (or `x0` in case you are using a SALT model) according to a desired absolute magnitude in a specific band by using the method `set_source_peakabsmag()`. Note that the redshift `z` affects your result. Therefore, you could specify:

```
>>> model.set(z=1.6)
>>> model.set_source_peakabsmag(-19.0, 'bessellb', 'ab')
```

Specifically, for SALT models, it is recommended to call `set_source_peakabsmag()` after setting the other model parameters, such as `x1` and `c`. It probably won't make a difference if you are using the 'bessellb' bandpass, but if you were setting the absolute magnitude in another band, it would make a small difference.

The reason for this peculiarity is that “absolute magnitude” is not a parameter in the SALT2 model, per se. The parameters are `x0`, `x1`, `c`, `t0`, and `z`. `x0` is a simple multiplicative scaling factor on the whole spectral timeseries. The `set_source_peakabsmag()` method is a convenience for setting `x0` such that the integrated flux through a given bandpass is as desired. Since the integrated flux depends on the spectral shape, it will depend on `x1` and `c`.

## 2.4 Creating a model with a source and effect(s)

Let's create a slightly more complex model. Again we will use the Hsiao spectral time series as a source, but this time we will add host galaxy dust.

```
>>> dust = sncosmo.CCM89Dust()
>>> model = sncosmo.Model(source='hsiao',
...                       effects=[dust],
...                       effect_names=['host'],
...                       effect_frames=['rest'])
```

The model now has additional parameters that describe the dust, `hostebv` and `hostr_v`:

```
>>> model.param_names
['z', 't0', 'amplitude', 'hostebv', 'hostr_v']
>>> model.parameters
array([ 0. ,  0. ,  1. ,  0. ,  3.1])
```

These are the parameters of the `CCM89Dust` instance we created:

```
>>> dust.param_names
['ebv', 'r_v']
```

In the model, the parameter names are prefixed with the name of the effect (`host`).

At any time you can print the model to get a nicely formatted string representation of its components and current parameter values:

```
>>> print(model)
<Model at 0x...>
source:
```

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```

class      : TimeSeriesSource
name       : hsiao
version    : 3.0
phases     : [-20, ..., 85] days (22 points)
wavelengths: [1000, ..., 25000] Angstroms (481 points)
effect (name='host' frame='rest'):
  class      : CCM89Dust
  wavelength range: [1250, 33333] Angstroms
parameters:
  z          = 0.0
  t0         = 0.0
  amplitude  = 1.0
  hostebv    = 0.0
  hostr_v    = 3.1000000000000001

```

Also, `str(model)` will return this string rather than printing it.

## 2.5 Adding Milky Way dust

Dust in the Milky Way will affect the shape of an observed supernova spectrum. It is important to take this into account in our model when fitting the model to observed data. As with host galaxy dust treated above, we can model Milky Way dust as a “propagation effect”. The only difference is that Milky Way dust is in the observer frame rather than the supernova rest frame. Here, we create a model with dust in *both* the SN rest frame and the observer frame:

```

>>> dust = sncosmo.CCM89Dust()
>>> model = sncosmo.Model(source='hsiao',
...                       effects=[dust, dust],
...                       effect_names=['host', 'mw'],
...                       effect_frames=['rest', 'obs'])

```

We can see that the model includes four extra parameters (two describing the host galaxy dust and two describing the milky way dust):

```

>>> model.param_names
['z', 't0', 'amplitude', 'hostebv', 'hostr_v', 'mwebv', 'mwr_v']
>>> model.parameters # default values
array([ 0. ,  0. ,  1. ,  0. ,  3.1,  0. ,  3.1])

```

The host galaxy dust parameters are prefixed with 'host' and the Milky Way dust parameters are prefixed with 'mw'. These are just the names we supplied when constructing the model. The effect names have no significance beyond this. The effect frames, on the other hand, *are* significant. The only allowed values are 'rest' (rest frame) and 'obs' (observer frame).

A typical use pattern is to get an estimate of the amount of Milky Way dust at the location of the supernova from a dust map, and then to fix that amount of dust in the model. The following example illustrates how to do this using the Schlegel, Finkbeiner and Davis (1998) dust map with the `sfdmap` package. First, load the dust map (do this only once):

```

>>> import sfdmap

>>> dustmap = sfdmap.SFDMap("/path/to/dust/maps")

```

Now, for each SN you wish to fit, get the amount of dust at the SN location and set the `mwebv` model parameter appropriately. For example, if the SN is located at RA=42.8 degrees, Dec=0 degrees:

```
>>> ebv = dustmap.ebv(42.8, 0.0)

>>> model.set(mwebv=ebv)

>>> # proceed with fitting the other model parameters to the data.
```

Note that we wish to *fix* the `mwebv` model parameter rather than fitting it to the data like the other parameters: We're supposing that this value is perfectly known from the dust map. Therefore, when using a function such as `fit_lc` to fit the parameters, be sure *not* to include 'mwebv' in the list of parameters to vary.

## 2.6 Model spectrum

To retrieve a spectrum (in ergs / s / cm<sup>2</sup> / Angstrom) at a given observer-frame time and set of wavelengths:

```
>>> wave = np.array([3000., 3500., 4000., 4500., 5000., 5500.])
>>> model.flux(-5., wave)
array([[ 5.29779465e-09,  7.77702880e-09,  7.13309678e-09,
         5.68369041e-09,  3.06860759e-09,  2.59024291e-09]])
```

We can supply a list or array of times and get a 2-d array back, representing the spectrum at each time:

```
>>> model.flux([-5., 2.], wave)
array([[ 5.29779465e-09,  7.77702880e-09,  7.13309678e-09,
         5.68369041e-09,  3.06860759e-09,  2.59024291e-09],
       [ 2.88166481e-09,  6.15186858e-09,  7.87880448e-09,
         6.93919846e-09,  3.59077596e-09,  3.27623932e-09]])
```

Changing the model parameters changes the results:

```
>>> model.parameters
array([0., 0., 1., 0., 3.1])
>>> model.flux(-5., [4000., 4500.])
array([ 7.13309678e-09,  5.68369041e-09])
>>> model.set(amplitude=2., hostebv=0.1)
>>> model.flux(-5., [4000., 4500.])
array([ 9.39081327e-09,  7.86972003e-09])
```

## 2.7 Synthetic photometry

To integrate the spectrum through a bandpass, use the `bandflux` method:

```
>>> model.bandflux('sdssi', -5.)
180213.72886169454
```

Here we are using the SDSS I band, at time -5. days. The return value is in photons / s / cm<sup>2</sup>. It is also possible to supply multiple times or bands:

```
>>> model.bandflux('sdssi', [-5., 2.])
array([ 180213.72886169, 176662.68287381])
>>> model.bandflux(['sdssi', 'sdssz'], [-5., -5.])
array([ 180213.72886169, 27697.76705621])
```

Instead of returning flux in photons / s / cm<sup>2</sup>, the flux can be normalized to a desired zeropoint by specifying the `zp` and `zpsys` keywords, which can also be scalars, lists, or arrays.

```
>>> model.bandflux(['sdssi', 'sdssz'], [-5., -5.], zp=25., zpsys='ab')
array([ 5.01036850e+09, 4.74414435e+09])
```

Instead of flux, magnitude can be returned. It works very similarly to flux:

```
>>> model.bandmag('sdssi', 'ab', [0., 1.])
array([ 22.6255077, 22.62566363])
>>> model.bandmag('sdssi', 'vega', [0., 1.])
array([ 22.26843273, 22.26858865])
```

We have been specifying the bandpasses as strings ('sdssi' and 'sdssz'). This works because these bandpasses are in the sncosmo “registry”. However, this is merely a convenience. In place of strings, we could have specified the actual *Bandpass* objects to which the strings correspond. See *Bandpasses* for more on how to directly create *Bandpass* objects.

The magnitude systems work similarly to bandpasses: 'ab' and 'vega' refer to built-in *MagSystem* objects, but you can also directly supply custom *MagSystem* objects. See *Magnitude Systems* for details.

## 2.8 Initializing Sources directly

You can initialize a source directly from your own template rather than using the built-in source templates.

### 2.8.1 Initializing a TimeSeriesSource

These sources are created directly from numpy arrays. Below, we build a very simple model, of a source with a flat spectrum at all times, rising from phase -50 to 0, then declining from phase 0 to +50.

```
>>> import numpy as np
>>> phase = np.linspace(-50., 50., 11)
>>> disp = np.linspace(3000., 8000., 6)
>>> flux = np.repeat(np.array([[0.], [1.], [2.], [3.], [4.], [5.],
...                           [4.], [3.], [2.], [1.], [0.]]),
...                 6, axis=1)
>>> source = sncosmo.TimeSeriesSource(phase, disp, flux)
```

Typically, you would then include this source in a *Model*:

```
>>> model = sncosmo.Model(source)
```

## 2.8.2 Initializing a SALT2Source

The SALT2 model is initialized directly from data files representing the model. You can initialize it by giving it a path to a directory containing the files.

```
>>> source = sncosmo.SALT2Source(modeldir='/path/to/dir')
```

By default, the initializer looks for files with names like 'salt2\_template\_0.dat', but this behavior can be altered with keyword parameters:

```
>>> source = sncosmo.SALT2Source(modeldir='/path/to/dir',  
...                               m0file='mytemplate0file.dat')
```

See [SALT2Source](#) for more details.





## BANDPASSES

### 3.1 Constructing a Bandpass

Bandpass objects represent the transmission fraction of an astronomical filter as a function of dispersion (photon wavelength, frequency or energy). They are basically simple containers for arrays of these values, with a couple special features. To get a bandpass that is in the registry (built-in):

```
>>> import sncosmo
>>> band = sncosmo.get_bandpass('sdssi')
>>> band
<Bandpass 'sdssi' at 0x...>
```

To create a Bandpass directly, you can supply arrays of wavelength and transmission values:

```
>>> wavelength = [4000., 5000.]
>>> transmission = [1., 1.]
>>> sncosmo.Bandpass(wavelength, transmission, name='tophatg')
<Bandpass 'tophatg' at 0x...>
```

By default, the first argument is assumed to be wavelength in Angstroms. To specify a different dispersion unit, use a unit from the `astropy.units` package:

```
>>> import astropy.units as u
>>> wavelength = [400., 500.]
>>> transmission = [1., 1.]
>>> Bandpass(wavelength, transmission, wave_unit=u.nm)
<Bandpass 'tophatg' at 0x...>
```

### 3.2 Using a Bandpass

A Bandpass acts like a continuous 1-d function, returning the transmission at supplied wavelengths (always in Angstroms):

```
>>> band([4100., 4250., 4300.])
array([ 0.,  1.,  1.]
```

Note that the transmission is zero outside the defined wavelength range. Linear interpolation is used between the defined wavelengths.

Bandpasses have a few other useful properties. You can get the range of wavelengths where the transmission is non-zero:

```
>>> band.minwave(), band.maxwave()
(4000.0, 5000.0)
```

Or the transmission-weighted effective wavelength:

```
>>> band.wave_eff
4500.0
```

Or the name:

```
>>> band.name
'tophatg'
```

### 3.3 Adding Bandpasses to the Registry

You can create your own bandpasses and use them like built-ins by adding them to the registry. Suppose we want to register the ‘tophatg’ bandpass we created:

```
>>> sncosmo.register(band, 'tophatg')
```

Or if `band.name` has been set:

```
>>> sncosmo.register(band) # registers band under band.name
```

After doing this, we can get the bandpass object by doing

```
>>> band = sncosmo.get_bandpass('tophatg')
```

Also, **we can pass the string ‘tophatg’ to any function that takes a *Bandpass* object**. This means that you can create and register bandpasses at the top of a script, then just keep track of string identifiers throughout the rest of the script.

## MAGNITUDE SYSTEMS

SNCosmo has facilities for converting synthetic model photometry to magnitudes in a variety of magnitude systems (or equivalently, scaling fluxes to a given zeropoint in a given magnitude system). For example, in the following code snippet, the string 'ab' specifies that we want magnitudes on the AB magnitude system:

```
>>> model.bandmag('desr', 'ab', [54990., 55000., 55020.])
```

The string 'ab' here refers to a built-in magnitude system ('vega' is another option). Behind the scenes magnitude systems are represented with *MagSystem* objects. As with *Bandpass* objects, most places in SNCosmo that require a magnitude system can take either the name of a magnitude system in the registry or an actual *MagSystem* instance. You can access these objects directly or create your own.

*MagSystem* objects represent the spectral flux density corresponding to magnitude zero in the given system and can be used to convert physical fluxes (in photons/s/cm<sup>2</sup>) to magnitudes. Here's an example:

```
>>> ab = sncosmo.get_magsystem('ab')
>>> ab.zpbandflux('sdssg')
546600.83408598113
```

This example gives the number of counts (in photons) when integrating the AB spectrum (which happens to be  $F_{\text{nu}} = 3631$  Jansky at all wavelengths) through the SDSS g band. This works similarly for other magnitude systems:

```
>>> vega = sncosmo.get_magsystem('vega')
>>> vega.zpbandflux('sdssg')
597541.25707788975
```

You can see that the Vega spectrum is a bit brighter than the AB spectrum in this particular bandpass. Therefore, SDSS g magnitudes given in Vega will be larger than if given in AB.

There are convenience methods for converting an observed flux in a bandpass to a magnitude:

```
>>> ab.band_flux_to_mag(1., 'sdssg')
14.344175725172901
>>> ab.band_mag_to_flux(14.344175725172901, 'sdssg')
0.99999999999999833
```

So, one count per second in this band is equivalent to an AB magnitude of about 14.34.

## 4.1 “Composite” magnitude systems

Sometimes, photometric data is reported in “magnitude systems” that don’t correspond directly to any spectrophotometric standard. One example is “SDSS magnitudes” which are like AB magnitudes but with an offset in each band. These are represented in SNCosmo with the *CompositeMagSystem* class. For example:

```
>>> magsys = sncosmo.CompositeMagSystem(bands={'sdssg': ('ab', 0.01),
...                                             'sdssr': ('ab', 0.02)})
```

This defines a new magnitude system that knows about only two bandpasses. In this magnitude system, an object with magnitude zero in AB would have a magnitude of 0.01 in SDSS *g* and 0.02 in SDSS *r*. Indeed, you can see that the flux corresponding to magnitude zero is slightly higher in this magnitude system than in AB:

```
>>> magsys.zpbandflux('sdssr')
502660.28545283229

>>> ab.zpbandflux('sdssr')
493485.70128115633
```

Since we’ve only defined the offsets for this magnitude system in a couple bands, using other bandpasses results in an error:

```
>>> magsys.zpbandflux('bessellb')
ValueError: band not defined in composite magnitude system
```

## PHOTOMETRIC DATA

### 5.1 Photometric data stored in AstroPy Table

In `sncosmo`, photometric data for a supernova is stored in an `astropy Table`: each row in the table is a photometric observation. The table must contain certain columns. To see what such a table looks like, you can load an example with the following function:

```
>>> data = sncosmo.load_example_data()
>>> print data
      time      band      flux      fluxerr      zp      zpsys
-----
    55070.0 sdssg    0.813499900062 0.651728140824 25.0      ab
55072.0512821 sdssr  -0.0852238865812 0.651728140824 25.0      ab
55074.1025641 sdssi  -0.00681659003089 0.651728140824 25.0      ab
55076.1538462 sdssz    2.23929135407 0.651728140824 25.0      ab
55078.2051282 sdssg  -0.0308977349373 0.651728140824 25.0      ab
55080.2564103 sdssr    2.35450321853 0.651728140824 25.0      ab
... etc ...
```

This example data table above has the minimum six columns necessary for `sncosmo`'s light curve fitting and plotting functions to interpret the data. (There's no harm in having more columns for other supplementary data.)

Additionally, metadata about the photometric data can be stored with the table: `data.meta` is an `OrderedDict` of the metadata.

### 5.2 Including Covariance

If your table contains a column `'fluxcov'` (or any similar name; see below) it will be interpreted as covariance between the data points and will be used *instead* of the `'fluxerr'` column when calculating a  $\chi^2$  value in fitting functions. For each row, the `'fluxcov'` column should be a length  $N$  array, where  $N$  is the number of rows in the table. In other words, `table['fluxcov']` should have shape  $(N, N)$ , where other columns like `table['time']` have shape  $(N,)$ .

As an example, let's add a `'fluxcov'` column to the example data table above.

```
>>> data['fluxcov'] = np.diag(data['fluxerr']**2)
>>> len(data)
40
>>> data['fluxcov'].shape
(40, 40)
```

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```
# diagonal elements are error squared:
>>> data['fluxcov'][0, 0]
0.45271884317377648

>>> data['fluxerr'][0]
0.67284384754100002

# off diagonal elements are zero:
>>> data['fluxcov'][0, 1]
0.0
```

As is, this would be completely equivalent to just having the 'fluxerr' column. But now we have the flexibility to represent non-zero off-diagonal covariance.

---

**Note:** When sub-selecting data from a table with covariance, be sure to use `sncosmo.select_data`. For example, rather than `table[mask]`, use `sncosmo.select_data(table, mask)`. This ensures that the covariance column is sliced appropriately! See the documentation for `select_data` for details.

---

## 5.3 Flexible column names

What if you'd rather call the time column 'date', or perhaps 'mjd'? Good news! SNCosmo is flexible about the column names. For each column, it accepts a variety of alias names:

Column	Acceptable aliases (case-independent)	Description	Type
time	'jd', 'mjd', 'mjdobs', 'time', 'date', 'mjd_obs'	Time of observation in days	float
band	'bandpass', 'band', 'filter', 'flt'	Bandpass of observation	str
flux	'f', 'flux'	Flux of observation	float
fluxerr	'flux_error', 'fluxerror', 'fluxerr', 'fe', 'flux_err'	Gaussian uncertainty on flux	float
zp	'zero_point', 'zeropoint', 'zeropt', 'zp', 'zpt'	Zeropoint corresponding to flux	float
zpsys	'zpmagsys', 'magsys', 'zpsys'	Magnitude system for zeropoint	str
fluxcov	'fluxcov', 'covariance', 'covmat', 'covar', 'cov'	Covariance between observations (array; optional)	ndarray

Note that each column must be present in some form or another, with no repeats. For example, you can have either a 'flux' column or a 'f' column, but not both.

The units of the flux and flux uncertainty are effectively given by the zeropoint system, with the zeropoint itself serving as a scaling factor: For example, if the zeropoint is 25.0 and the zeropoint system is 'vega', a flux of 1.0 corresponds to  $10^{(-25/2.5)}$  times the integrated flux of Vega in the given bandpass.

## 5.4 Reading and Writing photometric data from files

SNCosmo strives to be agnostic with respect to file format. In practice there are a plethora of different file formats, both standard and non-standard, used to represent tables. Rather than picking a single supported file format, or worse, creating yet another new “standard”, we choose to leave the file format mostly up to the user: A user can use any file format as long as they can read their data into an `astropy Table`.

That said, SNCosmo does include a couple convenience functions for reading and writing tables of photometric data: `sncosmo.read_lc` and `sncosmo.write_lc`:

```
>>> data = sncosmo.load_example_data()
>>> sncosmo.write_lc(data, 'test.txt')
```

This creates an output file `test.txt` that looks like:

```
@x1 0.5
@c 0.2
@z 0.5
@x0 1.20482820761e-05
@t0 55100.0
time band flux fluxerr zp zpsys
55070.0 sdssg 0.36351153597 0.672843847541 25.0 ab
55072.0512821 sdssr -0.200801295864 0.672843847541 25.0 ab
55074.1025641 sdssi 0.307494232981 0.672843847541 25.0 ab
55076.1538462 sdssz 1.08776103656 0.672843847541 25.0 ab
55078.2051282 sdssg -0.43667895645 0.672843847541 25.0 ab
55080.2564103 sdssr 1.09780966779 0.672843847541 25.0 ab
... etc ...
```

Read the file back in:

```
>>> data2 = sncosmo.read_lc('test.txt')
```

There are a few other available formats, which can be specified using the `format` keyword:

```
>>> data = sncosmo.read_lc('test.json', format='json')
```

The supported formats are listed below. If your preferred format is not included, use a standard reader/writer from `astropy` or the Python universe.

Format name	Description	Notes
ascii (default)	ASCII with metadata lines marked by '@'	Not readable by standard ASCII table parsers due to meta-data lines.
json	JavaScript Object Notation	Good performance, but not as human-readable as ascii
salt2	SALT2 new-style data files	
salt2-old	SALT2 old-style data files	

## 5.5 Manipulating data tables

Because photometric data tables are astropy Tables, they can be manipulated any way that Tables can. Here's a few things you might want to do.

Rename a column:

```
>>> data.rename_column('oldname', 'newname')
```

Add a column:

```
>>> data['zp'] = 26.
```

Add a constant value to all the entries in a given column:

```
>>> data['zp'] += 0.03
```

See the documentation on astropy tables for more information.



## SPECTRA

Spectroscopic observations are supported in `sncosmo` with the `Spectrum` class. A spectrum object can be created from a list of wavelengths and flux values:

```
>>> wave, flux, fluxerr = sncosmo.load_example_spectrum_data()
>>> spectrum = sncosmo.Spectrum(wave, flux)
```

By default, the wavelengths are assumed to be in angstroms and the flux values as a spectral flux density ( $\text{erg} / \text{s} / \text{cm}^2 / \text{\AA}$ ).

### 6.1 Uncertainties

A spectrum can have associated uncertainties. This can be either uncorrelated uncertainties for each spectral element:

```
>>> spectrum = sncosmo.Spectrum(wave, flux, fluxerr)
```

or a full covariance matrix:

```
>>> fluxcov = np.diag(fluxerr**2) + 1e-5 * np.max(flux)**2
>>> spectrum = sncosmo.Spectrum(wave, flux, fluxcov=fluxcov)
```

All operations will take these uncertainties into account.

### 6.2 Synthetic photometry

Synthetic photometry can be calculated on a spectrum using any of the bandpasses available in `sncosmo`:

```
>>> spectrum.bandflux('sdssg')
6.417843339246818
```

Synthetic photometry can be calculated on multiple bands simultaneously:

```
>>> spectrum.bandflux(['sdssg', 'sdssr', 'sdssi'])
array([6.41784334, 5.37683496, 2.8626649 ])
```

If a zeropoint and magnitude system are specified, then the bandflux is returned in that system (otherwise it is in photons  $/ \text{s} / \text{cm}^2$  by default).

```
>>> spectrum.bandflux(['sdssg', 'sdssr', 'sdssi'], zp=25., zpsys='ab')
array([117413.72315598, 108956.25581652, 79592.47424074])
```

Optionally, the full covariance matrix between the bandfluxes can also be calculated:

```
>>> spectrum.bandfluxcov(['sdssg', 'sdssr', 'sdssi'], zp=25., zpsys='ab')
(array([117413.72315598, 108956.25581652, 79592.47424074]),
 array([[1546972.78077853, 874550.34470817, 1287550.14818921],
        [ 874550.34470817, 2479812.26652077, 2226272.0481113 ],
        [1287550.14818921, 2226272.0481113 , 3805168.84485814]]))
```

A band magnitude can be evaluated in a specific magnitude system:

```
>>> spectrum.bandmag(['sdssg', 'sdssr', 'sdssi'], magsys='ab')
array([12.32570285, 12.40686957, 12.74781999])
```

## 6.3 Rebinning a spectrum

A spectrum can be rebinned with arbitrary wavelength bins. This returns a new *Spectrum* object.

```
>>> binned_spectrum = spectrum.rebin(np.arange(3500, 6000, 100))
```

Rebinning introduces covariance between adjacent spectral elements if the bin edges in the original spectrum don't line up with the bin edges in the rebinned spectrum. This covariance is properly propagated.

## 6.4 Fitting with spectra

Spectra can be used in fits. Any combination of spectra and photometry is allowed. To fit spectra, the times at which the spectra were taken must be specified. For example, to fit a single spectrum:

```
# Create the spectrum object, and specify the time at which it was taken.
>>> spectrum = sncosmo.Spectrum(wave, flux, fluxerr, time=20.)

# Fit a model to the spectrum.
>>> model = sncosmo.Model(source='hsiao-subsampled')
>>> sncosmo.fit_lc(model=model, spectra=spectrum,
...               vparam_names=['amplitude', 't0', 'z'],
...               bounds={'z': (0., 0.3)})
(
  success: True
  message: 'Minimization exited successfully.'
  ncall: 108
  chisq: 576.7111360163605
  ndof: 597
  param_names: ['z', 't0', 'amplitude']
  parameters: array([9.96571945e-02, 1.80278503e+01, 1.00650322e-05])
  vparam_names: ['z', 't0', 'amplitude']
  covariance: array([[ 1.17946556e-07,  1.64336679e-05, -5.21279026e-12],
                    [ 1.64336679e-05,  1.70047614e-02, -4.60755668e-09],
                    [-5.21279026e-12, -4.60755668e-09,  2.91915780e-15]])
  errors: OrderedDict([('z', 0.00034343314287464677),
                      ('t0', 0.13040215158608248),
                      ('amplitude', 5.4029230945864686e-08)])
  nfit: 1
```

(continues on next page)

(continued from previous page)

```
data_mask: None,  
<sncosmo.models.Model at 0x7fa30159a6d0>)
```

Other valid signatures are:

```
# photometry only  
>>> sncosmo.fit_lc(photometry, model, ...)  
  
# a single spectrum  
>>> sncosmo.fit_lc(model=model, spectra=spectrum, ...)  
  
# multiple spectra  
>>> sncosmo.fit_lc(model=model, spectra=[spec_1, spec_2], ...)  
  
# spectra and photometry simultaneously  
>>> sncosmo.fit_lc(photometry, model, spectra=[spec_1, spec_2], ...)
```



## APPLYING CUTS

It is useful to be able to apply “cuts” to data before trying to fit a model to the data. This is particularly important when using some of the “guessing” algorithms in *fit\_lc* and *nest\_lc* that use a minimum signal-to-noise ratio to pick “good” data points. These algorithms will raise an exception if there are no data points meeting the requirements, so it is advisable to check if the data meets the requirements beforehand.

### 7.1 Signal-to-noise ratio cuts

Require at least one datapoint with signal-to-noise ratio (S/N) greater than 5 (in any band):

```
>>> passes = np.max(data['flux'] / data['fluxerr']) > 5.  
>>> passes  
True
```

Require two bands each with at least one datapoint having  $S/N > 5$ :

```
>>> mask = data['flux'] / data['fluxerr'] > 5.  
>>> passes = len(np.unique(data['band'][mask])) >= 2  
>>> passes  
True
```



## SIMULATION

First, define a set of “observations”. These are the properties of our observations: the time, bandpass and depth.

```
import sncosmo
from astropy.table import Table
obs = Table({'time': [56176.19, 56188.254, 56207.172],
            'band': ['desg', 'desr', 'desi'],
            'gain': [1., 1., 1.],
            'skynoise': [191.27, 147.62, 160.40],
            'zp': [30., 30., 30.],
            'zpsys': ['ab', 'ab', 'ab']})
print obs
```

skynoise	zpsys	band	gain	time	zp
191.27	ab	desg	1.0	56176.19	30.0
147.62	ab	desr	1.0	56188.254	30.0
160.4	ab	desi	1.0	56207.172	30.0

Suppose we want to simulate a SN with the SALT2 model and the following parameters:

```
model = sncosmo.Model(source='salt2')
params = {'z': 0.4, 't0': 56200.0, 'x0': 1.e-5, 'x1': 0.1, 'c': -0.1}
```

To get the light curve for this single SN, we’d do:

```
lcs = sncosmo.realize_lcs(obs, model, [params])
print lcs[0]
```

time	band	flux	fluxerr	zp	zpsys
56176.19	desg	96.0531272705	191.27537908	30.0	ab
56188.254	desr	456.360196623	149.22627064	30.0	ab
56207.172	desi	655.40885611	162.579572369	30.0	ab

Note that we’ve passed the function a one-element list, [params], and gotten back a one-element list in return. (The realize\_lcs function is designed to operate on lists of SNe for convenience.)

## 8.1 Generating SN parameters

We see above that it is straightforward to simulate SNe once we already know the parameters of each one. But what if we want to pick SN parameters from some defined distribution?

Suppose we want to generate SN parameters for all the SNe we would find in a given search area over a defined period of time. We start by defining an area and time period, as well as a maximum redshift to consider:

```
area = 1. # area in square degrees
tmin = 56175. # minimum time
tmax = 56225. # maximum time
zmax = 0.7
```

First, we'd like to get the number and redshifts of all SNe that occur over our 1 square degree and 50 day time period:

```
redshifts = list(sncosmo.zdist(0., zmax, time=(tmax-tmin), area=area))
print len(redshifts), "SNe"
print "redshifts:", redshifts
```

```
9 SNe
redshifts: [0.4199710008856507, 0.3500118339133868, 0.5915676316485601, 0.
→5857452631151785, 0.49024466410556855, 0.5732679644841575, 0.6224436826380927, 0.
→5853477892182203, 0.5522300320124105]
```

Generate a list of SN parameters using these redshifts, drawing  $x_1$  and  $c$  from normal distributions:

```
from numpy.random import uniform, normal
params = [{ 'x0': 1.e-5, 'x1': normal(0., 1.), 'c': normal(0., 0.1),
            't0': uniform(tmin, tmax), 'z': z }
          for z in redshifts]
for p in params:
    print p
```

```
{ 'z': 0.4199710008856507, 'x0': 1e-05, 'x1': -0.9739877070754421, 'c': -0.
→1465835504611458, 't0': 56191.57686616353}
{ 'z': 0.3500118339133868, 'x0': 1e-05, 'x1': 0.04454878604727126, 'c': -0.
→04920811869083081, 't0': 56222.76963606611}
{ 'z': 0.5915676316485601, 'x0': 1e-05, 'x1': -0.26765265677262423, 'c': -0.
→06456008680932701, 't0': 56211.706219411404}
{ 'z': 0.5857452631151785, 'x0': 1e-05, 'x1': 0.8255953341731204, 'c': 0.
→08520083775049729, 't0': 56209.33583211229}
{ 'z': 0.49024466410556855, 'x0': 1e-05, 'x1': -0.12051827966517584, 'c': -0.
→09490756669333822, 't0': 56189.37571007927}
{ 'z': 0.5732679644841575, 'x0': 1e-05, 'x1': 0.3051310078192594, 'c': -0.
→10967604820261241, 't0': 56198.04368422346}
{ 'z': 0.6224436826380927, 'x0': 1e-05, 'x1': -0.6329407028587257, 'c': -0.
→009789183239376284, 't0': 56179.88133113836}
{ 'z': 0.5853477892182203, 'x0': 1e-05, 'x1': 0.6373371286596669, 'c': 0.
→05151693090038232, 't0': 56212.04579735962}
{ 'z': 0.5522300320124105, 'x0': 1e-05, 'x1': 0.04762095339856289, 'c': -0.
→005018877828783951, 't0': 56182.14827040906}
```

So far so good. The only problem is that  $x_0$  doesn't vary. We'd like it to be randomly distributed with some scatter around the Hubble line, so it should depend on the redshift. Here's an alternative:



```

params = []
for z in redshifts:
    mabs = normal(-19.3, 0.3)
    model.set(z=z)
    model.set_source_peakabsmag(mabs, 'bessellb', 'ab')
    x0 = model.get('x0')
    p = {'z':z, 't0':uniform(tmin, tmax), 'x0':x0, 'x1': normal(0., 1.), 'c': normal(0., 1.)}
    params.append(p)

for p in params:
    print p

```

```

{'c': -0.060104568346581566, 'x0': 2.9920355958896461e-05, 'z': 0.4199710008856507, 'x1': -0.677121283126299, 't0': 56217.93979718883}
{'c': 0.10405991801014292, 'x0': 2.134500759148091e-05, 'z': 0.3500118339133868, 'x1': 1.6034252041294512, 't0': 56218.008314206476}
{'c': -0.14777109151711296, 'x0': 7.9108889725043354e-06, 'z': 0.5915676316485601, 'x1': -2.2082282760850993, 't0': 56218.013686428785}
{'c': 0.056034777154805086, 'x0': 6.6457371815973038e-06, 'z': 0.5857452631151785, 'x1': 0.675413080007434, 't0': 56189.03517395757}
{'c': -0.0709158052635228, 'x0': 1.2228145655148946e-05, 'z': 0.49024466410556855, 'x1': 0.5449847454420981, 't0': 56198.02895700289}
{'c': -0.22101146234021096, 'x0': 7.4299221264917702e-06, 'z': 0.5732679644841575, 'x1': -1.543245858395605, 't0': 56189.04585414441}
{'c': 0.06964843664572477, 'x0': 9.7121906557832662e-06, 'z': 0.6224436826380927, 'x1': 1.7419604610283943, 't0': 56212.827270197355}
{'c': 0.07320513053870191, 'x0': 3.22205341646521e-06, 'z': 0.5853477892182203, 'x1': -0.39658066375434153, 't0': 56200.421464066916}
{'c': 0.18555773972769227, 'x0': 7.5955258508017471e-06, 'z': 0.5522300320124105, 'x1': -0.24463691193386283, 't0': 56190.492271332616}

```

Now we can generate the lightcurves for these parameters:

```

lcs = sncosmo.realize_lcs(obs, model, params)
print lcs[0]

```

time	band	flux	fluxerr	zp	zpsys
56176.19	desg	6.70520005464	191.27	30.0	ab
56188.254	desr	106.739113709	147.62	30.0	ab
56207.172	desi	1489.7521011	164.62420476	30.0	ab

Note that the “true” parameters are saved in the metadata of each SN:

```
lcs[0].meta
```

```

{'c': -0.060104568346581566,
 't0': 56217.93979718883,
 'x0': 2.9920355958896461e-05,
 'x1': -0.677121283126299,
 'z': 0.4199710008856507}

```



## REGISTRY

## 9.1 What is it?

The registry (`sncosmo.registry`) is responsible for translating string identifiers to objects, for user convenience. For example, it is used in `sncosmo.get_bandpass` and `sncosmo.get_source` to return a *Bandpass* or *sncosmo.Model* object based on the name of the bandpass or model:

```
>>> sncosmo.get_bandpass('sdssi')
<Bandpass 'sdssi' at 0x28e7c90>
```

It is also used in methods like `bandflux` to give it the ability to accept either a *Bandpass* object or the name of a bandpass:

```
>>> model = sncosmo.Model(source='hsiao')
>>> model.bandflux('sdssg', 0.) # works, thanks to registry.
```

Under the covers, the `bandflux` method retrieves the *Bandpass* corresponding to 'sdssg' by calling the `sncosmo.get_bandpass` function.

The registry is actually quite simple: it basically amounts to a dictionary and a few functions for accessing the dictionary. Most of the time, a user doesn't need to know anything about the registry. However, it is useful if you want to add your own “built-ins” or change the name of existing ones.

## 9.2 Using the registry to achieve custom “built-ins”

There are a small set of “built-in” models, bandpasses, and magnitude systems. But what if you want additional ones?

Create a file `mydefs.py` that registers all your custom definitions:

```
# contents of mydefs.py
import numpy as np
import sncosmo

wave = np.array([4000., 4200., 4400., 4600., 4800., 5000.])
trans = np.array([0., 1., 1., 1., 1., 0.])
band = sncosmo.Bandpass(wave, trans, name='tophatg')

sncosmo.registry.register(band)
```

Make sure `mydefs.py` is somewhere in your `$PYTHONPATH` or the directory you are running your main script from. Now in your script import your definitions at the beginning:

```
>>> import sncosmo
>>> import mydefs
>>> # ... proceed as normal
>>> # you can now use 'tophatg' as a built-in
```

## 9.3 Changing the name of built-ins

To change the name of the 'sdssg' band to 'SDSS\_G':

```
# contents of mydefs.py
import sncosmo

band = sncosmo.get_bandpass('sdssg')
band.name = 'SDSS_G'
sncosmo.register(band)
```

## 9.4 Large built-ins

What if your built-ins are really big or you have a lot of them? You might only want to load them as they are needed, rather than having to load everything into memory when you do `import mydefs`. You can use the `sncosmo.registry.register_loader` function. Suppose we have a bandpass that requires a huge data file (In reality it is unlikely that loading bandpasses would take a noticeable amount of time, but it might for models or spectra.):

```
# contents of mydefs.py
import sncosmo

def load_bandpass(filename, name=None, version=None):
    # ...
    # read data from filename, create a Bandpass object, "band"
    # ...
    return band

filename = 'path/to/datafile/for/huge_tophatg'
sncosmo.register_loader(
    sncosmo.Bandpass,      # class of object returned.
    'huge_tophatg',        # name
    load_bandpass,         # function that does the loading
    [filename]             # arguments to pass to function
)
```

Now when you `import mydefs` the registry will know how to load the *Bandpass* named 'huge\_tophatg' when it is needed. When loaded, it will be saved in memory so that subsequent operations don't need to load it again.

## DIRECTORY CONFIGURATION

The “built-in” Sources and Spectra in SNCosmo depend on some sizable data files. These files are hosted remotely, downloaded as needed, and cached locally. This all happens automatically, but it is helpful to know where the files are stored if you want to inspect them or share a common download directory between multiple users.

By default, SNCosmo will create and use an `sncosmo` subdirectory in the AstroPy cache directory for this purpose. For example, `$HOME/.astropy/cache/sncosmo`. After using a few models and spectra for the first time, here is what that directory might look like:

```
$ tree ~/.astropy/cache/sncosmo
/home/kyle/.astropy/cache/sncosmo
├── models
│   ├── hsiao
│   │   └── Hsiao_SED_V3.fits
│   └── sako
│       ├── S11_SDSS-000018.SED
│       ├── S11_SDSS-001472.SED
│       └── S11_SDSS-002000.SED
└── spectra
    ├── alpha_lyr_stis_007.fits
    └── bd_17d4708_stisnic_005.fits
```

You can see that within the top-level `$HOME/.astropy/cache/sncosmo` directory, a particular directory structure is created. This directory structure is fixed in the code, so it’s best not to move things around within the top-level directory. If you do, `sncosmo` will think the data have not been downloaded and will re-download them.

### 10.1 Configuring the Directories

What if you would rather use a different directory to store downloaded data? Perhaps you’d rather the data not be in a hidden directory, or perhaps there are multiple users who wish to use a shared data directory. There are two options:

1. Set the environment variable `SNCOSMO_DATA_DIR` to the directory you wish to use. For example, in bash:

```
export SNCOSMO_DATA_DIR=/home/user/data/sncosmo
```

If this environment variable is set, it takes precedence over the second option (below).

2. Set the `data_dir` variable in the `sncosmo` configuration file. This file is found in the `astropy` configuration directory, e.g., `$HOME/.astropy/config/sncosmo.cfg`. When you `import sncosmo` it checks for this file and creates a default one if it doesn’t exist. The default one looks like this:

```
$ cat ~/.astropy/config/sncosmo.cfg

## Directory containing SFD (1998) dust maps, with names:
## 'SFD_dust_4096_ngp.fits' and 'SFD_dust_4096_sgp.fits'
## Example: sfd98_dir = /home/user/data/sfd98
# sfd98_dir = None

## Directory where sncosmo will store and read downloaded data resources.
## If None, ASTROPY_CACHE_DIR/sncosmo will be used.
## Example: data_dir = /home/user/data/sncosmo
# data_dir = None
```

To change the data directory, simply uncomment the last line and set it to the desired directory. You can even move the data directory around, as long as you update this configuration parameter accordingly.

**orphan**

## EXAMPLES

### 11.1 Fitting a light curve

This example shows how to fit the parameters of a SALT2 model to photometric light curve data.

First, we'll load an example of some photometric data.

```
import sncosmo

data = sncosmo.load_example_data()

print(data)
```

Out:

time	band	flux	fluxerr	zp	zpsys
-----					
55070.0	sdssg	0.36351153597	0.672843847541	25.0	ab
55072.0512821	sdssr	-0.200801295864	0.672843847541	25.0	ab
55074.1025641	sdssi	0.307494232981	0.672843847541	25.0	ab
55076.1538462	sdssz	1.08776103656	0.672843847541	25.0	ab
55078.2051282	sdssg	-0.43667895645	0.672843847541	25.0	ab
55080.2564103	sdssr	1.09780966779	0.672843847541	25.0	ab
55082.3076923	sdssi	3.7562685627	0.672843847541	25.0	ab
55084.3589744	sdssz	5.34858894966	0.672843847541	25.0	ab
55086.4102564	sdssg	2.82614187269	0.672843847541	25.0	ab
55088.4615385	sdssr	7.56547045054	0.672843847541	25.0	ab
...	...	...	...	...	...
55129.4871795	sdssr	2.6597485586	0.672843847541	25.0	ab
55131.5384615	sdssi	3.99520404021	0.672843847541	25.0	ab
55133.5897436	sdssz	5.73989458094	0.672843847541	25.0	ab
55135.6410256	sdssg	0.330702283107	0.672843847541	25.0	ab
55137.6923077	sdssr	0.565286726579	0.672843847541	25.0	ab
55139.7435897	sdssi	3.04318346795	0.672843847541	25.0	ab
55141.7948718	sdssz	5.62692686384	0.672843847541	25.0	ab
55143.8461538	sdssg	-0.722654789013	0.672843847541	25.0	ab
55145.8974359	sdssr	1.12091764262	0.672843847541	25.0	ab
55147.9487179	sdssi	2.1246695264	0.672843847541	25.0	ab
55150.0	sdssz	5.3482175645	0.672843847541	25.0	ab
Length = 40 rows					

An important additional note: a table of photometric data has a `band` column and a `zpsys` column that use strings to identify the bandpass (e.g., 'sdssg') and zeropoint system ('ab') of each observation. If the bandpass and zeropoint systems in your data are *not* built-ins known to sncosmo, you must register the corresponding *Bandpass* or *MagSystem* to the right string identifier using the registry.

```
# create a model
model = sncosmo.Model(source='salt2')

# run the fit
result, fitted_model = sncosmo.fit_lc(
    data, model,
    ['z', 't0', 'x0', 'x1', 'c'], # parameters of model to vary
    bounds={'z':(0.3, 0.7)}) # bounds on parameters (if any)
```

Out:

```
Downloading http://sncosmo.github.io/data/models/salt2/salt2-4.tar.gz [Done]
Downloading http://sncosmo.github.io/data/bandpasses/sdss/sdss_g.dat [Done]
Downloading http://sncosmo.github.io/data/bandpasses/sdss/sdss_r.dat [Done]
Downloading http://sncosmo.github.io/data/bandpasses/sdss/sdss_i.dat [Done]
Downloading http://sncosmo.github.io/data/bandpasses/sdss/sdss_z.dat [Done]
```

The first object returned is a dictionary-like object where the keys can be accessed as attributes in addition to the typical dictionary lookup like `result['ncall']`:

```
print("Number of chi^2 function calls:", result.ncall)
print("Number of degrees of freedom in fit:", result.ndof)
print("chi^2 value at minimum:", result.chisq)
print("model parameters:", result.param_names)
print("best-fit values:", result.parameters)
print("The result contains the following attributes:\n", result.keys())
```

Out:

```
Number of chi^2 function calls: 133
Number of degrees of freedom in fit: 35
chi^2 value at minimum: 33.80988236076306
model parameters: ['z', 't0', 'x0', 'x1', 'c']
best-fit values: [5.15154859e-01 5.51004778e+04 1.19625368e-05 4.67270999e-01
 1.93951997e-01]
The result contains the following attributes:
dict_keys(['success', 'message', 'ncall', 'chisq', 'ndof', 'param_names', 'parameters',
↪ 'vparam_names', 'covariance', 'errors', 'nfit', 'data_mask'])
```

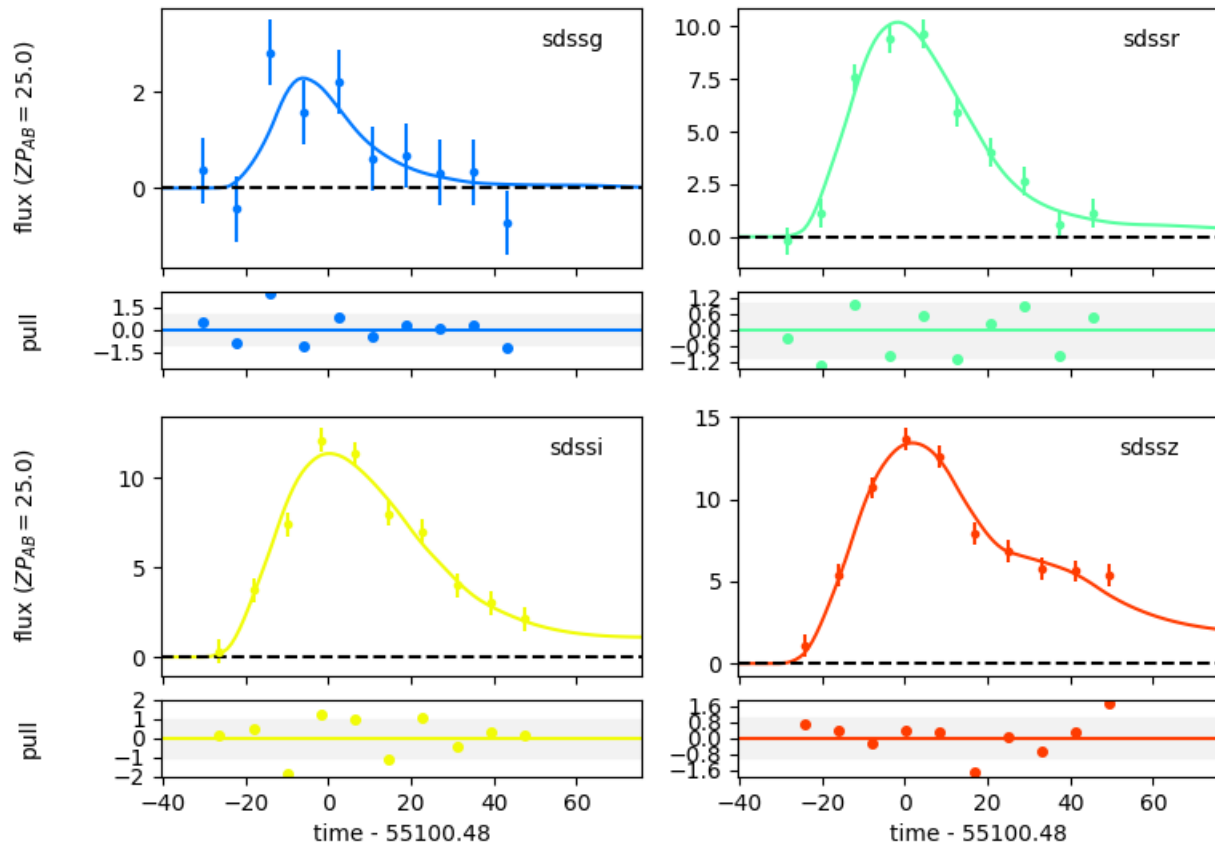
The second object returned is a shallow copy of the input model with the parameters set to the best fit values. The input model is unchanged.

```
sncosmo.plot_lc(data, model=fitted_model, errors=result.errors)
```



$z = 0.515 \pm 0.015$   
 $t_0 = 55100.48 \pm 0.42$   
 $x_0 = (1.196 \pm 0.039) \times 10^{-5}$

$x_1 = 0.47 \pm 0.32$   
 $c = 0.194 \pm 0.037$



Out:

<Figure size 780x670 with 8 Axes>

Suppose we already know the redshift of the supernova we're trying to fit. We want to set the model's redshift to the known value, and then make sure not to vary  $z$  in the fit.

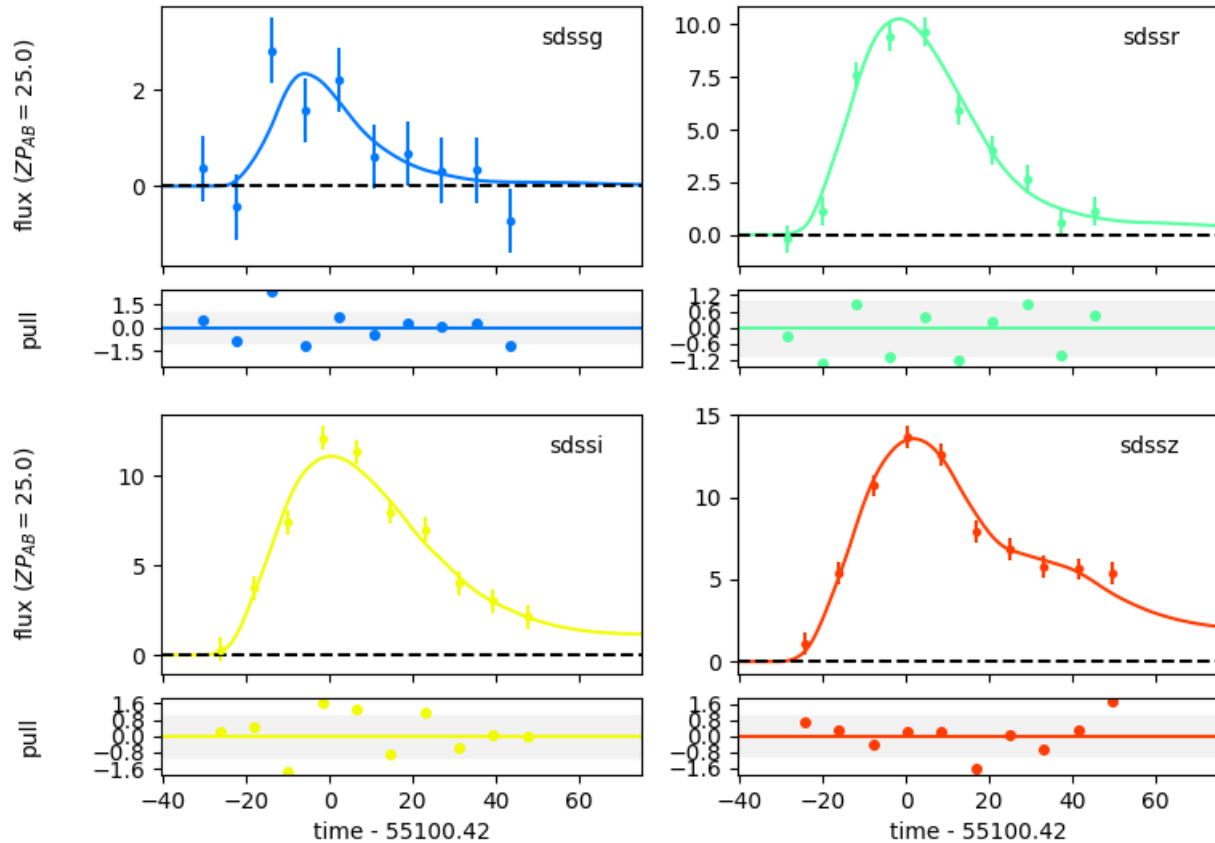
```

model.set(z=0.5) # set the model's redshift.
result, fitted_model = sncosmo.fit_lc(data, model,
                                     ['t0', 'x0', 'x1', 'c'])
sncosmo.plot_lc(data, model=fitted_model, errors=result.errors)

```

$z = 0.50000000$   
 $t_0 = 55100.42 \pm 0.41$   
 $x_0 = (1.181 \pm 0.038) \times 10^{-5}$

$x_1 = 0.55 \pm 0.34$   
 $c = 0.221 \pm 0.029$



Out:

<Figure size 780x670 with 8 Axes>

**Total running time of the script:** ( 0 minutes 2.275 seconds)

## 11.2 Using a custom fitter or sampler

How to use your own minimizer or MCMC sampler for fitting light curves.

SNCosmo has three functions for model parameter estimation based on photometric data: `sncosmo.fit_lc`, `sncosmo.mcmc_lc` and `sncosmo.nest_lc`. These are wrappers around external minimizers or samplers (respectively: `iminuit`, `emcee` and `nestle`). However, one may wish to experiment with a custom fitting or sampling method.

Here, we give a minimal example of using the L-BFGS-B minimizer from `scipy`.

```
import numpy as np
from scipy.optimize import fmin_l_bfgs_b
import sncosmo
```

(continues on next page)

(continued from previous page)

```

model = sncosmo.Model(source='salt2')
data = sncosmo.load_example_data()

# Define an objective function that we will pass to the minimizer.
# The function arguments must comply with the expectations of the specific
# minimizer you are using.
def objective(parameters):
    model.parameters[:] = parameters # set model parameters

    # evaluate model fluxes at times/bandpasses of data
    model_flux = model.bandflux(data['band'], data['time'],
                                zp=data['zp'], zpsys=data['zpsys'])

    # calculate and return chi^2
    return np.sum(((data['flux'] - model_flux) / data['fluxerr'])**2)

# starting parameter values in same order as `model.param_names`:
start_parameters = [0.4, 55098., 1e-5, 0., 0.] # z, t0, x0, x1, c

# parameter bounds in same order as `model.param_names`:
bounds = [(0.3, 0.7), (55080., 55120.), (None, None), (None, None),
          (None, None)]

parameters, val, info = fmin_l_bfgs_b(objective, start_parameters,
                                     bounds=bounds, approx_grad=True)

print(parameters)

```

Out:

```
[ 4.25872745e-01  5.50980000e+04  1.10751214e-05 -4.88112786e-03
  3.53962673e-01]
```

The built-in parameter estimation functions in sncosmo take care of setting up the likelihood function in the way that the underlying fitter or sampler expects. Additionally, they set guesses and bounds and package results up in a way that is as consistent as possible. For users wishing use a custom minimizer or sampler, it can be instructive to look at the source code for these functions.

**Total running time of the script:** ( 0 minutes 0.505 seconds)

## 11.3 Creating a new Source class

Extending sncosmo with a custom type of Source.

A Source is something that specifies a spectral timeseries as a function of an arbitrary number of parameters. For example, the SALT2 model has three parameters (`x0`, `x1` and `c`) that determine a unique spectrum as a function of phase. The `SALT2Source` class implements the behavior of the model: how the spectral time series depends on those parameters.

If you have a spectral timeseries model that follows the behavior of one of the existing classes, such as `TimeSeriesSource`, great! There's no need to write a custom class. However, suppose you want to implement a model that has some new parameterization. In this case, you need a new class that implements the behavior.

In this example, we implement a new type of source model. Our model is a linear combination of two spectral time series, with a parameter  $w$  that determines the relative weight of the models.

```
import numpy as np
from scipy.interpolate import RectBivariateSpline
import sncosmo

class ComboSource(sncosmo.Source):

    _param_names = ['amplitude', 'w']
    param_names_latex = ['A', 'w']  # used in plotting display

    def __init__(self, phase, wave, flux1, flux2, name=None, version=None):
        self.name = name
        self.version = version
        self._phase = phase
        self._wave = wave

        # ensure that fluxes are on the same scale
        flux2 = flux1.max() / flux2.max() * flux2

        self._model_flux1 = RectBivariateSpline(phase, wave, flux1, kx=3, ky=3)
        self._model_flux2 = RectBivariateSpline(phase, wave, flux2, kx=3, ky=3)
        self._parameters = np.array([1., 0.5])  # initial parameters

    def _flux(self, phase, wave):
        amplitude, w = self._parameters
        return amplitude * ((1.0 - w) * self._model_flux1(phase, wave) +
                           w * self._model_flux2(phase, wave))
```

... and that's all that we need to define!: A couple class attributes (`_param_names` and `param_names_latex`, an `__init__` method, and a `_flux` method. The `_flux` method is guaranteed to be passed numpy arrays for phase and wavelength.

We can now initialize an instance of this source from two spectral time series:

```
#Just as an example, we'll use some undocumented functionality in
# sncosmo to download the Nugent Ia and 2p templates. Don't rely on this
# the `DATADIR` object, or these paths in your code though, as these are
# subject to change between version of sncosmo!
from sncosmo.builtins import DATADIR
phase1, wave1, flux1 = sncosmo.read_griddata_ascii(
    DATADIR.abspath('models/nugent/sn1a_flux.v1.2.dat'))
phase2, wave2, flux2 = sncosmo.read_griddata_ascii(
    DATADIR.abspath('models/nugent/sn2p_flux.v1.2.dat'))

# In our __init__ method we defined above, the two fluxes need to be on
# the same grid, so interpolate the second onto the first:
flux2_interp = RectBivariateSpline(phase2, wave2, flux2)(phase1, wave1)

source = ComboSource(phase1, wave1, flux1, flux2_interp, name='sn1a+sn2p')
```

Out:

```
Downloading http://c3.lbl.gov/nugent/templates/sn1a_flux.v1.2.dat.gz [Done]
Downloading http://c3.lbl.gov/nugent/templates/sn2p_flux.v1.2.dat.gz [Done]
```

We can get a summary of the Source we created:

```
print(source)
```

Out:

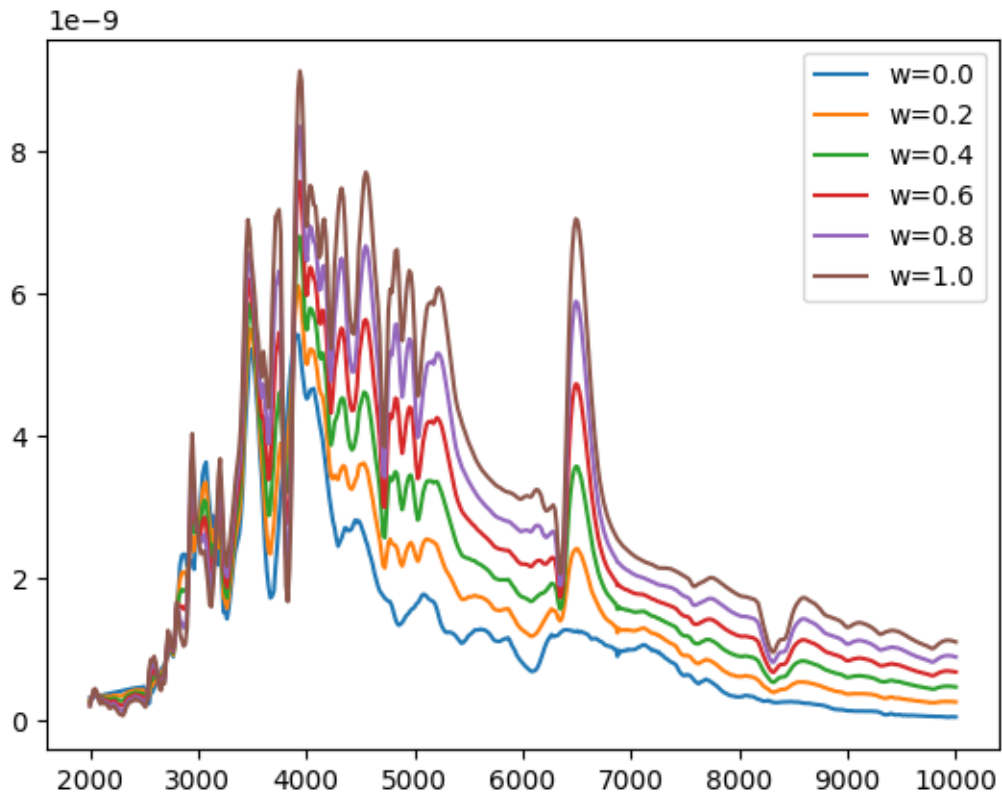
```
class      : ComboSource
name       : 'sn1a+sn2p'
version    : None
phases     : [0, .., 90] days
wavelengths: [1000, .., 25000] Angstroms
parameters:
  amplitude = 1.0
  w         = 0.5
```

Get a spectrum at phase 10 for different parameters:

```
from matplotlib import pyplot as plt

wave = np.linspace(2000.0, 10000.0, 500)
for w in (0.0, 0.2, 0.4, 0.6, 0.8, 1.0):
    source.set(w=w)
    plt.plot(wave, source.flux(10., wave), label='w={:3.1f}'.format(w))

plt.legend()
plt.show()
```



The  $w=0$  spectrum is that of the Ia model, the  $w=1$  spectrum is that of the IIp model, while intermediate spectra are weighted combinations.

We can even fit the model to some data!

```
model = sncosmo.Model(source=source)
data = sncosmo.load_example_data()
result, fitted_model = sncosmo.fit_lc(data, model,
                                     ['z', 't0', 'amplitude', 'w'],
                                     bounds={'z': (0.2, 1.0),
                                             'w': (0.0, 1.0)})

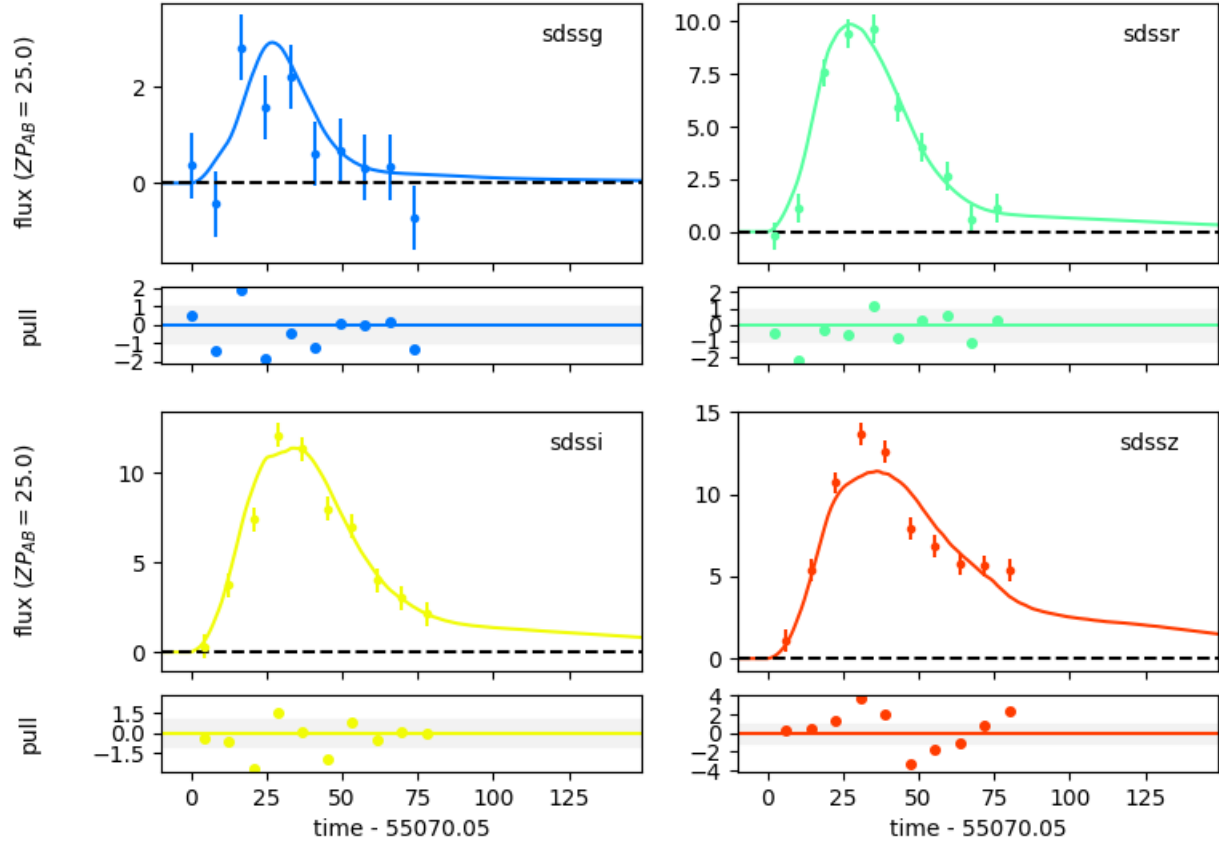
sncosmo.plot_lc(data, model=fitted_model, errors=result.errors)
```

$$z = 0.657 \pm 0.013$$

$$t_0 = 55070.05 \pm 0.64$$

$$A = (7.14 \pm 0.13) \times 10^{-10}$$

$$w = 0.218 \pm 0.054$$



Out:

<Figure size 780x670 with 8 Axes>

The fact that the fitted value of  $w$  is closer to 0 than 1 indicates that the light curve looks more like the Ia template than the Iip template. This is generally what we expected since the example data here was generated from a Ia template (although not the Nugent template!).

**Total running time of the script:** ( 0 minutes 2.984 seconds)

## 11.4 Examples

## 11.5 Reference / API

### 11.5.1 Model & Components

---

<code>Model(source[, effects, effect_names, ...])</code>	An observer-frame model, composed of a Source and zero or more effects.
--	---

---

#### sncosmo.Model

**class** sncosmo.**Model**(*source*, *effects*=None, *effect\_names*=None, *effect\_frames*=None)

An observer-frame model, composed of a Source and zero or more effects.

##### Parameters

**source** [[Source](#) or str] The model for the spectral evolution of the source. If a string is given, it is used to retrieve a [Source](#) from the registry.

**effects** [list of [PropagationEffect](#)] List of [PropagationEffect](#) instances to add.

**effect\_names** [list of str] Names of effects (same length as **effects**). The names are used to label the parameters.

**effect\_frames** [list of str] The frame that each effect is in (same length as **effects**). Must be one of {'rest', 'obs'}.

##### Notes

The Source and PropagationEffects are copied upon instantiation.

##### Examples

```
>>> model = sncosmo.Model(source='hsiao')
```

```
__init__(source, effects=None, effect_names=None, effect_frames=None)
```

##### Methods

---

<code>__init__(source[, effects, effect_names, ...])</code>	
<code>add_effect(effect, name, frame)</code>	Add a PropagationEffect to the model.
<code>bandflux(band, time[, zp, zpsys])</code>	Flux through the given bandpass(es) at the given time(s).
<code>bandfluxcov(band, time[, zp, zpsys])</code>	Like bandflux(), but also returns model covariance on values.
<code>bandmag(band, magsys, time)</code>	Magnitude at the given time(s) through the given bandpass(es), and for the given magnitude system(s).

---

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Table 2 – continued from previous page

<code>bandoverlap(band[, z])</code>	Return True if model dispersion range fully overlaps the band.
<code>color(band1, band2, magsys, time)</code>	band1 - band2 color at the given time(s) through the given pair of bandpasses, and for the given magnitude system.
<code>flux(time, wave)</code>	The spectral flux density at the given time and wavelength values.
<code>get(name)</code>	Get parameter of the model by name.
<code>maxtime()</code>	Maximum observer-frame time at which the model is defined.
<code>maxwave()</code>	Maximum observer-frame wavelength of the model.
<code>mintime()</code>	Minimum observer-frame time at which the model is defined.
<code>minwave()</code>	Minimum observer-frame wavelength of the model.
<code>set(**param_dict)</code>	Set parameters of the model by name.
<code>set_source_peakabsmag(absmag, band, magsys)</code>	Set the amplitude of the source component of the model according to the desired absolute magnitude in the specified band.
<code>set_source_peakmag(m, band, magsys[, sampling])</code>	Set the amplitude of the source component of the model according to a peak apparent magnitude.
<code>source_peakabsmag(band, magsys[, sampling, ...])</code>	Peak absolute magnitude of the source in rest-frame bandpass.
<code>source_peakmag(band, magsys[, sampling])</code>	Peak apparent magnitude of source in a rest-frame bandpass.
<code>update(param_dict)</code>	Set parameters of the model from a dictionary.

### Attributes

<code>effect_names</code>	Names of propagation effects (list of str).
<code>effects</code>	List of constituent propagation effects.
<code>param_names</code>	List of parameter names.
<code>parameters</code>	Parameter value array
<code>source</code>	The Source instance.

### Source component of Model

<code>Source()</code>	An abstract base class for transient models.
<code>TimeSeriesSource(phase, wave, flux[, ...])</code>	A single-component spectral time series model.
<code>StretchSource(phase, wave, flux[, name, version])</code>	A single-component spectral time series model, that "stretches" in time.
<code>MLCS2k2Source(fluxfile[, name, version])</code>	A spectral time series model based on the MLCS2k2 model light curves, using the Hsiao template at each phase, mangled to match the model photometry.
<code>SALT2Source([modelfile, m0file, m1file, ...])</code>	The SALT2 Type Ia supernova spectral timeseries model.
<code>SALT3Source([modelfile, m0file, m1file, ...])</code>	The SALT3 Type Ia supernova spectral timeseries model.
<code>SNEMOSource(fluxfile[, name, version])</code>	The SNEMO Type Ia supernova spectral timeseries model

continues on next page

Table 4 – continued from previous page

<code>SUGARSource</code> ([modeldir, m0file, alpha1file, ...])	The SUGAR Type Ia supernova spectral time series template.
--	--

## sncosmo.Source

### class sncosmo.Source

An abstract base class for transient models.

A “transient model” in this case is the spectral time evolution of a source, as defined in the rest-frame of the transient: `Source` subclass instances define a spectral flux density (in, e.g.,  $\text{erg} / \text{s} / \text{cm}^2 / \text{\AA}$ ) as a function of phase and wavelength, where phase and wavelength are in the source’s rest-frame. (The `Model` class wraps a `Source` instance and takes care of redshift and time dilation.) This two-dimensional spectral surface can be a function of any number of parameters that alter its amplitude or shape. Different subclasses will have different parameters.

This is an abstract base class – You can’t create instances of this class. Instead, you must work with subclasses such as `TimeSeriesSource`. Subclasses must define (at minimum):

- `__init__()`
- `_param_names` (list of str)
- `_parameters` (`numpy.ndarray`)
- `_flux(ndarray, ndarray)`
- `minphase()`
- `maxphase()`
- `minwave()`
- `maxwave()`

**abstract** `__init__()`

### Methods

<code>__init__()</code>	
<code>bandflux(band, phase[, zp, zpsys])</code>	Flux through the given bandpass(es) at the given phase(s).
<code>bandmag(band, magsys, phase)</code>	Magnitude at the given phase(s) through the given bandpass(es), and for the given magnitude system(s).
<code>flux(phase, wave)</code>	The spectral flux density at the given phase and wavelength values.
<code>get(name)</code>	Get parameter of the model by name.
<code>maxphase()</code>	
<code>maxwave()</code>	
<code>minphase()</code>	

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Table 5 – continued from previous page

<code>minwave()</code>	
<code>peakmag(band, magsys[, sampling])</code>	Peak apparent magnitude in rest-frame bandpass.
<code>peakphase(band_or_wave[, sampling])</code>	Determine phase of maximum flux for the given band/wavelength.
<code>set(**param_dict)</code>	Set parameters of the model by name.
<code>set_peakmag(m, band, magsys[, sampling])</code>	Set peak apparent magnitude in rest-frame bandpass.
<code>update(param_dict)</code>	Set parameters of the model from a dictionary.

### Attributes

<code>param_names</code>	List of parameter names.
<code>parameters</code>	Parameter value array

## sncosmo.TimeSeriesSource

**class** `sncosmo.TimeSeriesSource`(*phase, wave, flux, zero\_before=False, time\_spline\_degree=3, name=None, version=None*)

A single-component spectral time series model.

The spectral flux density of this model is given by

$$F(t, \lambda) = A \times M(t, \lambda)$$

where `_M_` is the flux defined on a grid in phase and wavelength and `_A_` (amplitude) is the single free parameter of the model. The amplitude `_A_` is a simple unitless scaling factor applied to whatever flux values are used to initialize the `TimeSeriesSource`. Therefore, the `_A_` parameter has no intrinsic meaning. It can only be interpreted in conjunction with the model values. Thus, it is meaningless to compare the `_A_` parameter between two different `TimeSeriesSource` instances with different model data.

### Parameters

**phase** [`ndarray`] Phases in days.

**wave** [`ndarray`] Wavelengths in Angstroms.

**flux** [`ndarray`] Model spectral flux density in  $\text{erg} / \text{s} / \text{cm}^2 / \text{Angstrom}$ . Must have shape `(num_phases, num_wave)`.

**zero\_before** [`bool`, optional] If `True`, flux at phases before minimum phase will be zeroed. The default is `False`, in which case the flux at such phases will be equal to the flux at the minimum phase (`flux[0, :]` in the input array).

**time\_spline\_degree** [`int`, optional] Degree of the spline used for interpolation in the time (phase) direction. By default this is set to 3 (i.e. cubic spline). For models that are defined with sparse time grids this can lead to large interpolation uncertainties and negative fluxes. If this is a problem, set `time_spline_degree` to 1 to use linear interpolation instead.

**name** [`str`, optional] Name of the model. Default is `None`.

**version** [`str`, optional] Version of the model. Default is `None`.

**\_\_init\_\_**(*phase, wave, flux, zero\_before=False, time\_spline\_degree=3, name=None, version=None*)

## Methods

<code>__init__(phase, wave, flux[, zero_before, ...])</code>	
<code>bandflux(band, phase[, zp, zpsys])</code>	Flux through the given bandpass(es) at the given phase(s).
<code>bandmag(band, magsys, phase)</code>	Magnitude at the given phase(s) through the given bandpass(es), and for the given magnitude system(s).
<code>flux(phase, wave)</code>	The spectral flux density at the given phase and wavelength values.
<code>get(name)</code>	Get parameter of the model by name.
<code>maxphase()</code>	
<code>maxwave()</code>	
<code>minphase()</code>	
<code>minwave()</code>	
<code>peakmag(band, magsys[, sampling])</code>	Peak apparent magnitude in rest-frame bandpass.
<code>peakphase(band_or_wave[, sampling])</code>	Determine phase of maximum flux for the given band/wavelength.
<code>set(**param_dict)</code>	Set parameters of the model by name.
<code>set_peakmag(m, band, magsys[, sampling])</code>	Set peak apparent magnitude in rest-frame bandpass.
<code>update(param_dict)</code>	Set parameters of the model from a dictionary.

## Attributes

<code>param_names</code>	List of parameter names.
<code>param_names_latex</code>	
<code>parameters</code>	Parameter value array

## sncosmo.StretchSource

**class** sncosmo.**StretchSource**(*phase, wave, flux, name=None, version=None*)

A single-component spectral time series model, that “stretches” in time.

The spectral flux density of this model is given by

$$F(t, \lambda) = A \times M(t/s, \lambda)$$

where `_A_` is the amplitude and `_s_` is the “stretch”.

### Parameters

**phase** [[ndarray](#)] Phases in days.

**wave** [[ndarray](#)] Wavelengths in Angstroms.

**flux** [[ndarray](#)] Model spectral flux density in erg / s / cm<sup>2</sup> / Angstrom. Must have shape (num\_phases, num\_disp).

`__init__(phase, wave, flux, name=None, version=None)`

## Methods

<code>__init__(phase, wave, flux[, name, version])</code>	
<code>bandflux(band, phase[, zp, zpsys])</code>	Flux through the given bandpass(es) at the given phase(s).
<code>bandmag(band, magsys, phase)</code>	Magnitude at the given phase(s) through the given bandpass(es), and for the given magnitude system(s).
<code>flux(phase, wave)</code>	The spectral flux density at the given phase and wavelength values.
<code>get(name)</code>	Get parameter of the model by name.
<code>maxphase()</code>	
<code>maxwave()</code>	
<code>minphase()</code>	
<code>minwave()</code>	
<code>peakmag(band, magsys[, sampling])</code>	Peak apparent magnitude in rest-frame bandpass.
<code>peakphase(band_or_wave[, sampling])</code>	Determine phase of maximum flux for the given band/wavelength.
<code>set(**param_dict)</code>	Set parameters of the model by name.
<code>set_peakmag(m, band, magsys[, sampling])</code>	Set peak apparent magnitude in rest-frame bandpass.
<code>update(param_dict)</code>	Set parameters of the model from a dictionary.

## Attributes

<code>param_names</code>	List of parameter names.
<code>param_names_latex</code>	
<code>parameters</code>	Parameter value array

## sncosmo.MLCS2k2Source

**class** sncosmo.MLCS2k2Source(*fluxfile, name=None, version=None*)

A spectral time series model based on the MLCS2k2 model light curves, using the Hsiao template at each phase, mangled to match the model photometry.

The spectral flux density of this model is given by

$$F(t, \lambda) = A \times M(\Delta, t, \lambda)$$

where `_A_` is the amplitude and `_Delta_` is the MLCS2k2 light curve shape parameter.

**Note:** Requires scipy version 0.14 or higher.

### Parameters

**fluxfile** [str or obj] Filename (or open file-like object) of a FITS file containing 3-d array of spectral flux density values for a grid of delta, phase and wavelength values.

`__init__` (*fluxfile*, *name=None*, *version=None*)

### Methods

---

<code>__init__</code> (fluxfile[, name, version])	
<code>bandflux</code> (band, phase[, zp, zpsys])	Flux through the given bandpass(es) at the given phase(s).
<code>bandmag</code> (band, magsys, phase)	Magnitude at the given phase(s) through the given bandpass(es), and for the given magnitude system(s).
<code>flux</code> (phase, wave)	The spectral flux density at the given phase and wavelength values.
<code>get</code> (name)	Get parameter of the model by name.
<code>maxphase</code> ()	
<code>maxwave</code> ()	
<code>minphase</code> ()	
<code>minwave</code> ()	
<code>peakmag</code> (band, magsys[, sampling])	Peak apparent magnitude in rest-frame bandpass.
<code>peakphase</code> (band_or_wave[, sampling])	Determine phase of maximum flux for the given band/wavelength.
<code>set</code> (**param_dict)	Set parameters of the model by name.
<code>set_peakmag</code> (m, band, magsys[, sampling])	Set peak apparent magnitude in rest-frame bandpass.
<code>update</code> (param_dict)	Set parameters of the model from a dictionary.

---

### Attributes

---

<code>param_names</code>	List of parameter names.
<code>param_names_latex</code>	
<code>parameters</code>	Parameter value array

---

## sncosmo.SALT2Source

```
class sncosmo.SALT2Source(modeldir=None, m0file='salt2_template_0.dat', m1file='salt2_template_1.dat',
                           clfile='salt2_color_correction.dat', cdfile='salt2_color_dispersion.dat',
                           errscalefile='salt2_lc_dispersion_scaling.dat',
                           lcrv00file='salt2_lc_relative_variance_0.dat',
                           lcrv11file='salt2_lc_relative_variance_1.dat',
                           lcrv01file='salt2_lc_relative_covariance_01.dat', name=None, version=None)
```

The SALT2 Type Ia supernova spectral timeseries model.

The spectral flux density of this model is given by

$$F(t, \lambda) = x_0(M_0(t, \lambda) + x_1 M_1(t, \lambda)) \times 10^{-0.4CL(\lambda)c}$$

where  $x_0$ ,  $x_1$  and  $c$  are the free parameters of the model,  $M_0$ ,  $M_1$  are the zeroth and first components of the model, and  $CL$  is the colorlaw, which gives the extinction in magnitudes for  $c=1$ .

### Parameters

**modeldir** [str, optional] Directory path containing model component files. Default is `None`, which means that no directory is prepended to filenames when determining their path.

**m0file**, **m1file**, **clfile** [str or fileobj, optional] Filenames of various model components. Defaults are:

- **m0file** = 'salt2\_template\_0.dat' (2-d grid)
- **m1file** = 'salt2\_template\_1.dat' (2-d grid)
- **clfile** = 'salt2\_color\_correction.dat'

**errscalefile**, **lcrv00file**, **lcrv11file**, **lcrv01file**, **cdfile** [str or fileobj] (optional) Filenames of various model components for model covariance in synthetic photometry. See `bandflux_rcov` for details. Defaults are:

- **errscalefile** = 'salt2\_lc\_dispersion\_scaling.dat' (2-d grid)
- **lcrv00file** = 'salt2\_lc\_relative\_variance\_0.dat' (2-d grid)
- **lcrv11file** = 'salt2\_lc\_relative\_variance\_1.dat' (2-d grid)
- **lcrv01file** = 'salt2\_lc\_relative\_covariance\_01.dat' (2-d grid)
- **cdfile** = 'salt2\_color\_dispersion.dat' (1-d grid)

### Notes

The “2-d grid” files have the format `<phase> <wavelength> <value>` on each line.

The phase and wavelength values of the various components don’t necessarily need to match. (In the most recent salt2 model data, they do not all match.) The phase and wavelength values of the first model component (in **m0file**) are taken as the “native” sampling of the model, even though these values might require interpolation of the other model components.

```
__init__(modeldir=None, m0file='salt2_template_0.dat', m1file='salt2_template_1.dat',
          clfile='salt2_color_correction.dat', cdfile='salt2_color_dispersion.dat',
          errscalefile='salt2_lc_dispersion_scaling.dat', lcrv00file='salt2_lc_relative_variance_0.dat',
          lcrv11file='salt2_lc_relative_variance_1.dat', lcrv01file='salt2_lc_relative_covariance_01.dat',
          name=None, version=None)
```

## Methods

<code>__init__([modeldir, m0file, m1file, clfile, ...])</code>	
<code>bandflux(band, phase[, zp, zpsys])</code>	Flux through the given bandpass(es) at the given phase(s).
<code>bandflux_rcov(band, phase)</code>	Return the <i>relative</i> model covariance (or "model error") on synthetic photometry generated from the model in the given restframe band(s).
<code>bandmag(band, magsys, phase)</code>	Magnitude at the given phase(s) through the given bandpass(es), and for the given magnitude system(s).
<code>colorlaw([wave])</code>	Return the value of the CL function for the given wavelengths.
<code>flux(phase, wave)</code>	The spectral flux density at the given phase and wavelength values.
<code>get(name)</code>	Get parameter of the model by name.
<code>maxphase()</code>	
<code>maxwave()</code>	
<code>minphase()</code>	
<code>minwave()</code>	
<code>peakmag(band, magsys[, sampling])</code>	Peak apparent magnitude in rest-frame bandpass.
<code>peakphase(band_or_wave[, sampling])</code>	Determine phase of maximum flux for the given band/wavelength.
<code>set(**param_dict)</code>	Set parameters of the model by name.
<code>set_peakmag(m, band, magsys[, sampling])</code>	Set peak apparent magnitude in rest-frame bandpass.
<code>update(param_dict)</code>	Set parameters of the model from a dictionary.

## Attributes

<code>param_names</code>	List of parameter names.
<code>param_names_latex</code>	
<code>parameters</code>	Parameter value array

## sncosmo.SALT3Source

```
class sncosmo.SALT3Source(modeldir=None, m0file='salt3_template_0.dat', m1file='salt3_template_1.dat',
                           clfile='salt3_color_correction.dat', cdfile='salt3_color_dispersion.dat',
                           lcrv00file='salt3_lc_variance_0.dat', lcrv11file='salt3_lc_variance_1.dat',
                           lcrv01file='salt3_lc_covariance_01.dat', name=None, version=None)
```

The SALT3 Type Ia supernova spectral timeseries model. Kenworthy et al., 2021, ApJ, submitted. Model definitions are the same as SALT2 except for the errors, which are now given in flux space. Unlike SALT2, no file is used for scaling the errors.



The spectral flux density of this model is given by

$$F(t, \lambda) = x_0(M_0(t, \lambda) + x_1 M_1(t, \lambda)) \times 10^{-0.4CL(\lambda)c}$$

where  $x_0$ ,  $x_1$  and  $c$  are the free parameters of the model,  $M_0$ ,  $M_1$  are the zeroth and first components of the model, and  $CL$  is the colorlaw, which gives the extinction in magnitudes for  $c=1$ .

### Parameters

**modeldir** [str, optional] Directory path containing model component files. Default is `None`, which means that no directory is prepended to filenames when determining their path.

**m0file**, **m1file**, **clfile** [str or fileobj, optional] Filenames of various model components. Defaults are:

- `m0file` = 'salt2\_template\_0.dat' (2-d grid)
- `m1file` = 'salt2\_template\_1.dat' (2-d grid)
- `clfile` = 'salt2\_color\_correction.dat'

**lcrv00file**, **lcrv11file**, **lcrv01file**, **cdfile** [str or fileobj] (optional) Filenames of various model components for model covariance in synthetic photometry. See `bandflux_rcov` for details. Defaults are:

- `lcrv00file` = 'salt2\_lc\_relative\_variance\_0.dat' (2-d grid)
- `lcrv11file` = 'salt2\_lc\_relative\_variance\_1.dat' (2-d grid)
- `lcrv01file` = 'salt2\_lc\_relative\_covariance\_01.dat' (2-d grid)
- `cdfile` = 'salt2\_color\_dispersion.dat' (1-d grid)

### Notes

The “2-d grid” files have the format `<phase> <wavelength> <value>` on each line.

The phase and wavelength values of the various components don’t necessarily need to match. (In the most recent salt2 model data, they do not all match.) The phase and wavelength values of the first model component (in `m0file`) are taken as the “native” sampling of the model, even though these values might require interpolation of the other model components.

```
__init__(modeldir=None, m0file='salt3_template_0.dat', m1file='salt3_template_1.dat',
         clfile='salt3_color_correction.dat', cdfile='salt3_color_dispersion.dat',
         lcrv00file='salt3_lc_variance_0.dat', lcrv11file='salt3_lc_variance_1.dat',
         lcrv01file='salt3_lc_covariance_01.dat', name=None, version=None)
```

### Methods

---

```
__init__([modeldir, m0file, m1file, clfile, ...])
```

---

<code>bandflux(band, phase[, zp, zpsys])</code>	Flux through the given bandpass(es) at the given phase(s).
<code>bandflux_rcov(band, phase)</code>	Return the <i>relative</i> model covariance (or "model error") on synthetic photometry generated from the model in the given restframe band(s).

---

continues on next page

Table 15 – continued from previous page

<code>bandmag(band, magsys, phase)</code>	Magnitude at the given phase(s) through the given bandpass(es), and for the given magnitude system(s).
<code>colorlaw([wave])</code>	Return the value of the CL function for the given wavelengths.
<code>flux(phase, wave)</code>	The spectral flux density at the given phase and wavelength values.
<code>get(name)</code>	Get parameter of the model by name.
<code>maxphase()</code>	
<code>maxwave()</code>	
<code>minphase()</code>	
<code>minwave()</code>	
<code>peakmag(band, magsys[, sampling])</code>	Peak apparent magnitude in rest-frame bandpass.
<code>peakphase(band_or_wave[, sampling])</code>	Determine phase of maximum flux for the given band/wavelength.
<code>set(**param_dict)</code>	Set parameters of the model by name.
<code>set_peakmag(m, band, magsys[, sampling])</code>	Set peak apparent magnitude in rest-frame bandpass.
<code>update(param_dict)</code>	Set parameters of the model from a dictionary.

### Attributes

<code>param_names</code>	List of parameter names.
<code>param_names_latex</code>	
<code>parameters</code>	Parameter value array

## sncosmo.SNEMOSource

**class** sncosmo.SNEMOSource(*fluxfile*, *name=None*, *version=None*)

The SNEMO Type Ia supernova spectral timeseries model

The spectral flux density of this model is given by

$$F(t, \lambda) = c_0(e_0(t, \lambda) + \sum_{i=1}^n c_i e_i(t, \lambda)) \times FM07(\lambda, A_s)$$

where `c_0`, `c_i`, and `A_s` are the free parameters of the model.

### Parameters

**fluxfile** [str or obj, optional] Filename of an ascii file containing 2-d array of spectral flux density values for a grid of phase and wavelength values. Assuming columns `phase`, `wavelength`, `e_0`, `e_1`, `e_2`...

**\_\_init\_\_**(*fluxfile*, *name=None*, *version=None*)

## Methods

<code>__init__(fluxfile[, name, version])</code>	
<code>bandflux(band, phase[, zp, zpsys])</code>	Flux through the given bandpass(es) at the given phase(s).
<code>bandmag(band, magsys, phase)</code>	Magnitude at the given phase(s) through the given bandpass(es), and for the given magnitude system(s).
<code>flux(phase, wave)</code>	The spectral flux density at the given phase and wavelength values.
<code>get(name)</code>	Get parameter of the model by name.
<code>maxphase()</code>	
<code>maxwave()</code>	
<code>minphase()</code>	
<code>minwave()</code>	
<code>peakmag(band, magsys[, sampling])</code>	Peak apparent magnitude in rest-frame bandpass.
<code>peakphase(band_or_wave[, sampling])</code>	Determine phase of maximum flux for the given band/wavelength.
<code>set(**param_dict)</code>	Set parameters of the model by name.
<code>set_peakmag(m, band, magsys[, sampling])</code>	Set peak apparent magnitude in rest-frame bandpass.
<code>update(param_dict)</code>	Set parameters of the model from a dictionary.

## Attributes

<code>param_names</code>	List of parameter names.
<code>parameters</code>	Parameter value array

## sncosmo.SUGARSource

```
class sncosmo.SUGARSource(modeldir=None, m0file='sugar_template_0.dat',
                           alpha1file='sugar_template_1.dat', alpha2file='sugar_template_2.dat',
                           alpha3file='sugar_template_3.dat', CCMfile='sugar_template_4.dat', name=None,
                           version=None)
```

The SUGAR Type Ia supernova spectral time series template.

The spectral energy distribution of this model is given by

$$F(t, \lambda) = q_0 10^{-0.4(M_0(t, \lambda) + q_1 \alpha_1(t, \lambda) + q_2 \alpha_2(t, \lambda) + q_3 \alpha_3(t, \lambda) + A_v CCM(\lambda))} (10^{-3} c \lambda^2)$$

where  $q_0$ ,  $q_1$ ,  $q_2$ ,  $q_3$ , and  $A_v$  are the free parameters of the model,  $\alpha_0$ ,  $\alpha_1$ ,  $\alpha_2$ ,  $\alpha_3$ ,  $CCM$  are the template vectors of the model. The  $q_0$  is the equivalent parameter in flux of the `Delta M_{gray}` parameter define in Leget et al. 2020.

### Parameters

**modeldir** [str, optional] Directory path containing model component files. Default is `None`, which means that no directory is prepended to filenames when determining their path.

**m0file** [str or fileobj, optional]

**alpha1file** [str or fileobj, optional]

**alpha2file** [str or fileobj, optional]

**alpha3file** [str or fileobj, optional]

**CCMfile: str or fileobj, optional** Filenames of various model components. Defaults are: \*  
m0file = 'sugar\_template\_0.dat' (2-d grid) \* alpha1file = 'sugar\_template\_1.dat' (2-d grid)  
\* alpha2file = 'sugar\_template\_2.dat' (2-d grid) \* alpha3file = 'sugar\_template\_3.dat' (2-d  
grid) \* CCMfile = 'sugar\_template\_4.dat' (2-d grid)

## Notes

The “2-d grid” files have the format <phase> <wavelength> <value> on each line.

```
__init__(modeldir=None, m0file='sugar_template_0.dat', alpha1file='sugar_template_1.dat',
        alpha2file='sugar_template_2.dat', alpha3file='sugar_template_3.dat',
        CCMfile='sugar_template_4.dat', name=None, version=None)
```

## Methods

<code>__init__</code> ([modeldir, m0file, alpha1file, ...])	
<code>bandflux</code> (band, phase[, zp, zpsys])	Flux through the given bandpass(es) at the given phase(s).
<code>bandmag</code> (band, magsys, phase)	Magnitude at the given phase(s) through the given bandpass(es), and for the given magnitude system(s).
<code>flux</code> (phase, wave)	The spectral flux density at the given phase and wavelength values.
<code>get</code> (name)	Get parameter of the model by name.
<code>maxphase</code> ()	
<code>maxwave</code> ()	
<code>minphase</code> ()	
<code>minwave</code> ()	
<code>peakmag</code> (band, magsys[, sampling])	Peak apparent magnitude in rest-frame bandpass.
<code>peakphase</code> (band_or_wave[, sampling])	Determine phase of maximum flux for the given band/wavelength.
<code>set</code> (**param_dict)	Set parameters of the model by name.
<code>set_peakmag</code> (m, band, magsys[, sampling])	Set peak apparent magnitude in rest-frame bandpass.
<code>update</code> (param_dict)	Set parameters of the model from a dictionary.

### Attributes

<code>param_names</code>	List of parameter names.
<code>param_names_latex</code>	
<code>parameters</code>	Parameter value array

*Effect components of Model: interstellar dust extinction*

<code>PropagationEffect()</code>	Abstract base class for propagation effects.
<code>CCM89Dust()</code>	Cardelli, Clayton, Mathis (1989) extinction model dust.
<code>OD94Dust()</code>	O'Donnell (1994) extinction model dust.
<code>F99Dust([r_v])</code>	Fitzpatrick (1999) extinction model dust with fixed R_V.

### sncosmo.PropagationEffect

**class** sncosmo.PropagationEffect

Abstract base class for propagation effects.

Derived classes must define `_minwave` (float), `_maxwave` (float).

`__init__(*args, **kwargs)`

### Methods

<code>__init__(*args, **kwargs)</code>	
<code>get(name)</code>	Get parameter of the model by name.
<code>maxwave()</code>	
<code>minwave()</code>	
<code>propagate(wave, flux)</code>	
<code>set(**param_dict)</code>	Set parameters of the model by name.
<code>update(param_dict)</code>	Set parameters of the model from a dictionary.

### Attributes

<code>param_names</code>	List of parameter names.
<code>parameters</code>	Parameter value array

## sncosmo.CCM89Dust

**class** sncosmo.CCM89Dust

Cardelli, Clayton, Mathis (1989) extinction model dust.

**\_\_init\_\_()**

### Methods

<code>__init__()</code>	
<code>get(name)</code>	Get parameter of the model by name.
<code>maxwave()</code>	
<code>minwave()</code>	
<code>propagate(wave, flux)</code>	Propagate the flux.
<code>set(**param_dict)</code>	Set parameters of the model by name.
<code>update(param_dict)</code>	Set parameters of the model from a dictionary.

### Attributes

<code>param_names</code>	List of parameter names.
<code>param_names_latex</code>	
<code>parameters</code>	Parameter value array

## sncosmo.OD94Dust

**class** sncosmo.OD94Dust

O'Donnell (1994) extinction model dust.

**\_\_init\_\_()**

### Methods

<code>__init__()</code>	
<code>get(name)</code>	Get parameter of the model by name.
<code>maxwave()</code>	
<code>minwave()</code>	
<code>propagate(wave, flux)</code>	Propagate the flux.
<code>set(**param_dict)</code>	Set parameters of the model by name.
<code>update(param_dict)</code>	Set parameters of the model from a dictionary.

**Attributes**

<code>param_names</code>	List of parameter names.
<code>param_names_latex</code>	
<code>parameters</code>	Parameter value array

**sncosmo.F99Dust**

**class** sncosmo.**F99Dust**(*r\_v=3.1*)  
 Fitzpatrick (1999) extinction model dust with fixed R\_V.  
**\_\_init\_\_**(*r\_v=3.1*)

**Methods**

<code>__init__</code> ([ <i>r_v</i> ])	
<code>get</code> ( <i>name</i> )	Get parameter of the model by name.
<code>maxwave</code> ()	
<code>minwave</code> ()	
<code>propagate</code> ( <i>wave</i> , <i>flux</i> )	Propagate the flux.
<code>set</code> (** <i>param_dict</i> )	Set parameters of the model by name.
<code>update</code> ( <i>param_dict</i> )	Set parameters of the model from a dictionary.

**Attributes**

<code>param_names</code>	List of parameter names.
<code>parameters</code>	Parameter value array

**11.5.2 Bandpass & Magnitude Systems**

<code>Bandpass</code> ( <i>wave</i> , <i>trans</i> [, <i>wave_unit</i> , ...])	Transmission as a function of spectral wavelength.
<code>AggregateBandpass</code> ( <i>transmissions</i> [, ...])	Bandpass defined by multiple transmissions in series.
<code>BandpassInterpolator</code> ( <i>transmissions</i> , ...[, ...])	Bandpass generator defined as a function of focal plane position.
<code>MagSystem</code> ([ <i>name</i> ])	An abstract base class for magnitude systems.
<code>ABMagSystem</code> ([ <i>name</i> ])	Magnitude system where a source with F_nu = 3631 Jansky at all frequencies has magnitude 0 in all bands.
<code>SpectralMagSystem</code> ( <i>refspectrum</i> [, <i>name</i> ])	A magnitude system defined by a fundamental spectrophotometric standard.
<code>CompositeMagSystem</code> ([ <i>bands</i> , <i>families</i> , <i>name</i> ])	A magnitude system defined in a specific set of bands.

## sncosmo.Bandpass

**class** sncosmo.Bandpass(*wave*, *trans*, *wave\_unit*=Unit('Angstrom'), *trans\_unit*=Unit(dimensionless), *normalize*=False, *name*=None, *trim\_level*=None)

Transmission as a function of spectral wavelength.

### Parameters

**wave** [list\_like] Wavelength. Monotonically increasing values.

**trans** [list\_like] Transmission fraction.

**wave\_unit** [Unit or str, optional] Wavelength unit. Default is Angstroms.

**trans\_unit** [Unit, optional] Transmission unit. Can be `dimensionless_unscaled`, indicating a ratio of transmitted to incident photons, or units proportional to inverse energy, indicating a ratio of transmitted photons to incident energy. Default is ratio of transmitted to incident photons.

**normalize** [bool, optional] If True, normalize fractional transmission to be 1.0 at peak. It is recommended to set `normalize=True` if transmission is in units of inverse energy. (When transmission is given in these units, the absolute value is usually not significant; normalizing gives more reasonable transmission values.) Default is False.

**trim\_level** [float, optional] If given, crop bandpass to region where transmission is above this fraction of the maximum transmission. For example, if maximum transmission is 0.5, `trim_level=0.001` will remove regions where transmission is below 0.0005. Only contiguous regions on the sides of the bandpass are removed.

**name** [str, optional] Identifier. Default is `None`.

### Examples

Construct a Bandpass and access the input arrays:

```
>>> b = Bandpass([4000., 4200., 4400.], [0.5, 1.0, 0.5])
>>> b.wave
array([ 4000.,  4200.,  4400.])
>>> b.trans
array([ 0.5,  1. ,  0.5])
```

Bandpasses act like continuous 1-d functions (linear interpolation is used):

```
>>> b([4100., 4300.])
array([ 0.75,  0.75])
```

The effective (transmission-weighted) wavelength is a property:

```
>>> b.wave_eff
4200.0
```

The `trim_level` keyword can be used to remove “out-of-band” transmission upon construction. The following example removes regions of the bandpass with transmission less than 1 percent of peak:

```
>>> band = Bandpass([4000., 4100., 4200., 4300., 4400., 4500.],
...                  [0.001, 0.002, 0.5, 0.6, 0.003, 0.001],
...                  trim_level=0.01)
```



```
>>> band.wave
array([ 4100.,  4200.,  4300.,  4400.]
```

```
>>> band.trans
array([ 0.002,  0.5   ,  0.6   ,  0.003])
```

While less strictly correct than including the “out-of-band” transmission, only considering the region of the bandpass where transmission is significant can improve model-bandpass overlap as well as performance.

```
__init__(wave, trans, wave_unit=Unit('Angstrom'), trans_unit=Unit(dimensionless), normalize=False,
          name=None, trim_level=None)
```

## Methods

---

```
__init__(wave, trans[, wave_unit, ...])
```

---

```
maxwave()
```

---

```
minwave()
```

---

<pre>shifted(factor[, name])</pre>	Return a new Bandpass instance with all wavelengths multiplied by a factor.
------------------------------------	---

---

## Attributes

<pre>wave_eff</pre>	Effective wavelength of bandpass in Angstroms.
---------------------	--

---

## sncosmo.AggregateBandpass

```
class sncosmo.AggregateBandpass(transmissions, prefactor=1.0, name=None, family=None)
```

Bandpass defined by multiple transmissions in series.

### Parameters

**transmissions** [list of (wave, trans) pairs.] Functions defining component transmissions.

**prefactor** [float, optional] Scalar factor to multiply transmissions by. Default is 1.0.

**name** [str, optional] Name of bandpass.

**family** [str, optional] Name of “family” this bandpass belongs to. Such an identifier can be useful for identifying bandpasses belonging to the same instrument/filter combination but different focal plane positions.

```
__init__(transmissions, prefactor=1.0, name=None, family=None)
```

## Methods

<code>__init__(transmissions[, prefactor, name, ...])</code>	
<code>maxwave()</code>	
<code>minwave()</code>	
<code>shifted(factor[, name, family])</code>	Return a new AggregateBandpass instance with all wavelengths multiplied by a factor.

## Attributes

<code>wave_eff</code>	Effective wavelength of bandpass in Angstroms.
-----------------------	--

## sncosmo.BandpassInterpolator

**class** sncosmo.BandpassInterpolator(*transmissions, dependent\_transmissions, prefactor=1.0, name=None*)  
 Bandpass generator defined as a function of focal plane position.

Instances of this class are not Bandpasses themselves, but generate Bandpasses at a given focal plane position. This class stores the transmission as a function of focal plane position and interpolates between the defined positions to return the bandpass at an arbitrary position.

### Parameters

- transmissions** [list of (wave, trans) pairs] Transmissions that apply everywhere in the focal plane.
- dependent\_transmissions** [list of (value, wave, trans)] Transmissions that depend on some parameter. Each value is the scalar parameter value, `wave` and `trans` are 1-d arrays.
- prefactor** [float, optional] Scalar multiplying factor.
- name** [str]

## Examples

Transmission uniform across focal plane:

```
>>> uniform_trans = ([4000., 5000.], [1., 0.5]) # wave, trans
```

Transmissions as a function of radius:

```
>>> trans0 = (0., [4000., 5000.], [0.5, 0.5]) # radius=0
>>> trans1 = (1., [4000., 5000.], [0.75, 0.75]) # radius=1
>>> trans2 = (2., [4000., 5000.], [0.1, 0.1]) # radius=2
```

```
>>> band_interp = BandpassInterpolator([uniform_trans],
...                                   [trans0, trans1, trans2],
...                                   name='my_band')
```

Min and max radius:

```
>>> band_interp.minpos(), band_interp.maxpos()
(0.0, 2.0)
```

Get bandpass at a given radius:

```
>>> band = band_interp.at(1.5)
```

```
>>> band
<AggregateBandpass 'my_band at 1.500000' at 0x7f7a2e425668>
```

The band is aggregate of uniform transmission part, and interpolated radial-dependent part.

```
>>> band([4500., 4600.])
array([ 0.65625,  0.6125 ])
```

```
__init__(transmissions, dependent_transmissions, prefactor=1.0, name=None)
```

## Methods

```
__init__(transmissions, dependent_transmissions)
```

<code>at(pos)</code>	Return the bandpass at the given position
<code>maxpos()</code>	Maximum positional parameter value.
<code>minpos()</code>	Minimum positional parameter value.

## sncosmo.MagSystem

**class** sncosmo.MagSystem(*name=None*)  
An abstract base class for magnitude systems.

```
__init__(name=None)
```

## Methods

```
__init__([name])
```

<code>band_flux_to_mag(flux, band)</code>	Convert flux (photons / s / cm <sup>2</sup> ) to magnitude.
<code>band_mag_to_flux(mag, band)</code>	Convert magnitude to flux in photons / s / cm <sup>2</sup>
<code>zpbbandflux(band)</code>	Flux of an object with magnitude zero in the given bandpass.

### Attributes

name	Name of magnitude system.
------	---------------------------

## sncosmo.ABMagSystem

**class** sncosmo.ABMagSystem(*name=None*)

Magnitude system where a source with  $F_{\nu} = 3631$  Jansky at all frequencies has magnitude 0 in all bands.

**\_\_init\_\_**(*name=None*)

### Methods

<b>__init__</b> ([name])	
band_flux_to_mag(flux, band)	Convert flux (photons / s / cm <sup>2</sup> ) to magnitude.
band_mag_to_flux(mag, band)	Convert magnitude to flux in photons / s / cm <sup>2</sup>
zpbandflux(band)	Flux of an object with magnitude zero in the given bandpass.

### Attributes

name	Name of magnitude system.
------	---------------------------

## sncosmo.SpectralMagSystem

**class** sncosmo.SpectralMagSystem(*refspectrum, name=None*)

A magnitude system defined by a fundamental spectrophotometric standard.

#### Parameters

**refspectrum** [sncosmo.SpectrumModel] The spectrum of the fundamental spectrophotometric standard.

**\_\_init\_\_**(*refspectrum, name=None*)

### Methods

<b>__init__</b> (refspectrum[, name])	
band_flux_to_mag(flux, band)	Convert flux (photons / s / cm <sup>2</sup> ) to magnitude.
band_mag_to_flux(mag, band)	Convert magnitude to flux in photons / s / cm <sup>2</sup>
zpbandflux(band)	Flux of an object with magnitude zero in the given bandpass.

## Attributes

name	Name of magnitude system.
------	---------------------------

## sncosmo.CompositeMagSystem

**class** sncosmo.CompositeMagSystem(*bands=None, families=None, name=None*)

A magnitude system defined in a specific set of bands.

In each band, there is a fundamental standard with a known (generally non-zero) magnitude.

### Parameters

**bands: dict, optional** Dictionary where keys are *Bandpass* instances or names, thereof and values are 2-tuples of magnitude system and offset. The offset gives the magnitude of standard in the given band. A positive offset means that the composite magsystem zeropoint flux is higher (brighter) than that of the standard.

**families** [dict, optional] Similar to the *bands* argument, but keys are strings that apply to any bandpass that has a matching *family* attribute. This is useful for generated bandpasses where the transmission differs across focal plane (and hence the bandpass at each position is unique), but all photometry has been calibrated to the same offset.

**name** [str] The name attribute of the magnitude system.

## Examples

Create a magnitude system defined in only two SDSS bands where an object with AB magnitude of 0 would have a magnitude of 0.01 and 0.02 in the two bands respectively:

```
>>> sncosmo.CompositeMagSystem(bands={'sdssg': ('ab', 0.01),
...                                     'sdssr': ('ab', 0.02)})
```

**\_\_init\_\_**(*bands=None, families=None, name=None*)

## Methods

<b>__init__</b> ([ <i>bands, families, name</i> ])	
<b>band_flux_to_mag</b> (flux, band)	Convert flux (photons / s / cm <sup>2</sup> ) to magnitude.
<b>band_mag_to_flux</b> (mag, band)	Convert magnitude to flux in photons / s / cm <sup>2</sup>
<b>zpbandflux</b> (band)	Flux of an object with magnitude zero in the given bandpass.

## Attributes

bands	
name	Name of magnitude system.

### 11.5.3 I/O

*Functions for reading and writing photometric data, gridded data, extinction maps, and more.*

<code>read_lc(file_or_dir[, format])</code>	Read light curve data for a single supernova.
<code>write_lc(data, fname[, format])</code>	Write light curve data.
<code>read_bandpass(fname[, fmt, wave_unit, ...])</code>	Read bandpass from two-column ASCII file containing wavelength and transmission in each line.
<code>load_example_data()</code>	Load an example photometric data table.
<code>load_example_spectrum_data()</code>	Load example spectrum data.
<code>read_snana_ascii(fname[, default_tablename])</code>	Read an SNANA-format ascii file.
<code>read_snana_fits(head_file, phot_file[, snids, n])</code>	Read the SNANA FITS format: two FITS files jointly representing metadata and photometry for a set of SNe.
<code>read_snana_simlib(fname)</code>	Read an SNANA 'simlib' (simulation library) ascii file.
<code>read_griddata_ascii(name_or_obj)</code>	Read 2-d grid data from a text file.
<code>read_griddata_fits(name_or_obj[, ext])</code>	Read a multi-dimensional grid of data from a FITS file, where the grid coordinates are encoded in the FITS-WCS header keywords.
<code>write_griddata_ascii(x0, x1, y, name_or_obj)</code>	Write 2-d grid data to a text file.
<code>write_griddata_fits(x0, x1, y, name_or_obj)</code>	Write a 2-d grid of data to a FITS file

## sncosmo.read\_lc

`sncosmo.read_lc(file_or_dir, format='ascii', **kwargs)`

Read light curve data for a single supernova.

### Parameters

**file\_or\_dir** [str] Filename (formats 'ascii', 'json', 'salt2') or directory name (format 'salt2-old'). For 'salt2-old' format, directory must contain a file named 'lightfile'. All other files in the directory are assumed to be photometry files, unless the `filenames` keyword argument is set.

**format** [{ 'ascii', 'json', 'salt2', 'salt2-old' }, optional] Format of file. Default is 'ascii'. 'salt2' is the new format available in snfit version >= 2.3.0.

**read\_covmat** [bool, optional] [**salt2 only**] If True, and if a COVMAT keyword is present in header, read the covariance matrix from the filename specified by COVMAT (assumed to be in the same directory as the lightcurve file) and include it as a column named `FLUXcov` in the returned table. Default is False.

*New in version 1.5.0*

**expand\_bands** [bool, optional] [**salt2 only**] If True, convert band names into equivalent Bandpass objects. This is particularly useful for position-dependent bandpasses in the salt2 file format: the position information is read from the header and used when creating the bandpass objects.

*New in version 1.5.0*

**delim** [str, optional] [**ascii only**] Used to split entries on a line. Default is `None`. Extra whitespace is ignored.

**metachar** [str, optional] [**ascii only**] Lines whose first non-whitespace character is `metachar` are treated as metadata lines, where the key and value are split on the first whitespace. Default is `'@'`.

**commentchar** [str, optional] [**ascii only**] One-character string indicating a comment. Default is `'#'`.

**filenames** [list, optional] [**salt2-old only**] Only try to read the given filenames as photometry files. Default is to try to read all files in directory.

### Returns

**t** [astropy [Table](#)] Table of data. Metadata (as an `OrderedDict`) can be accessed via the `t.meta` attribute. For example: `t.meta['key']`. The key is case-sensitive.

## Examples

Read an ascii format file that includes metadata (StringIO behaves like a file object):

```
>>> from io import StringIO
>>> f = StringIO('''
... @id 1
... @RA 36.0
... @description good
... time band flux fluxerr zp zpsys
... 50000. g 1. 0.1 25. ab
... 50000.1 r 2. 0.1 25. ab
... ''')
>>> t = read_lc(f, format='ascii')
>>> print(t)
  time band flux fluxerr zp zpsys
-----
50000.0   g  1.0      0.1 25.0   ab
50000.1   r  2.0      0.1 25.0   ab
>>> t.meta
OrderedDict([('id', 1), ('RA', 36.0), ('description', 'good')])
```

## sncosmo.write\_lc

`sncosmo.write_lc(data, fname, format='ascii', **kwargs)`

Write light curve data.

### Parameters

**data** [[Table](#)] Light curve data.

**fname** [str] Filename.

**format** [{`'ascii'`, `'salt2'`, `'snana'`, `'json'`}, optional] Format of file. Default is `'ascii'`. `'salt2'` is the new format available in snfit version `>= 2.3.0`.

**delim** [str, optional] [**ascii only**] Character used to separate entries on a line. Default is `' '`.

**metachar** [str, optional] [**ascii only**] Metadata designator. Default is '@'.

**raw** [bool, optional] [**salt2, snana**] By default, the SALT2 and SNANA writers rename some metadata keys and column names in order to comply with what snfit and SNANA expect. Set to True to override this. Default is False.

**pedantic** [bool, optional] [**salt2, snana**] If True, check that output column names and header keys comply with expected formatting, and raise a ValueError if not. It is probably a good idea to set to False when raw is True. Default is True.

## sncosmo.read\_bandpass

```
sncosmo.read_bandpass(fname, fmt='ascii', wave_unit=Unit('Angstrom'), trans_unit=Unit('dimensionless'),
                      normalize=False, trim_level=None, name=None)
```

Read bandpass from two-column ASCII file containing wavelength and transmission in each line.

### Parameters

**fname** [str] File name.

**fmt** [{ 'ascii' }] File format of file. Currently only ASCII file supported.

**wave\_unit** [Unit or str, optional] Wavelength unit. Default is Angstroms.

**trans\_unit** [Unit, optional] Transmission unit. Can be `dimensionless_unscaled`, indicating a ratio of transmitted to incident photons, or units proportional to inverse energy, indicating a ratio of transmitted photons to incident energy. Default is ratio of transmitted to incident photons.

**normalize** [bool, optional] If True, normalize fractional transmission to be 1.0 at peak. It is recommended to set to True if transmission is in units of inverse energy. (When transmission is given in these units, the absolute value is usually not significant; normalizing gives more reasonable transmission values.) Default is False.

**name** [str, optional] Identifier. Default is `None`.

### Returns

**band** [*Bandpass*]

## sncosmo.load\_example\_data

```
sncosmo.load_example_data()
```

Load an example photometric data table.

### Returns

**data** [Table]



## sncosmo.load\_example\_spectrum\_data

`sncosmo.load_example_spectrum_data()`

Load example spectrum data.

### Returns

**wave** [array] Wavelengths of each spectral bin

**flux** [array] Flux in each spectral bin

**fluxerr** [array] Flux error in each spectral bin

## sncosmo.read\_snana\_ascii

`sncosmo.read_snana_ascii(fname, default_tablename=None)`

Read an SNANA-format ascii file.

Such files may contain metadata lines and one or more tables. See Notes for a summary of the format.

### Parameters

**fname** [str] Filename of object to read.

**default\_tablename** [str, optional] Default tablename, or the string that indicates a table row, when a table starts with 'NVAR:' rather than 'NVAR\_TABLENAME:'.

**array** [bool, optional] If True, each table is converted to a numpy array. If False, each table is a dictionary of lists (each list is a column). Default is True.

### Returns

**meta** [OrderedDict] Metadata from keywords.

**tables** [dict of Table] Tables, indexed by table name.

## Notes

The file can contain one or more tables, as well as optional metadata. Here is an example of the expected format:

```

META1: a
META2: 6
NVAR_SN: 3
VARNAMES: A B C
SN: 1 2.0 x
SN: 4 5.0 y

```

Behavior:

- Any strings ending in a colon (:) are treated as keywords.
- The start of a new table is indicated by a keyword starting with 'NVAR'.
- If the 'NVAR' is followed by an underscore (e.g., 'NVAR\_TABLENAME'), then 'TABLENAME' is taken to be the name of the table. Otherwise the user *must specify* a `default_tablename`. This is because data rows are identified by the tablename.
- After a keyword starting with 'NVAR', the next keyword must be 'VARNAMES'. The strings following give the column names.

- Any other keywords anywhere in the file are treated as metadata. The first string after the keyword is treated as the value for that keyword.
- **Note:** Newlines are treated as equivalent to spaces; they do not indicate a new row. This is necessary because some SNANA-format files have multiple metadata on a single row or single table rows split over multiple lines, making newline characters meaningless.

## Examples

```
>>> from io import StringIO # StringIO behaves like a file
>>> f = StringIO('META1: a\n'
...              'META2: 6\n'
...              'NVAR_SN: 3\n'
...              'VARNAMES: A B C\n'
...              'SN: 1 2.0 x\n'
...              'SN: 4 5.0 y\n')
>>> meta, tables = read_snana_ascii(f)
```

The first object is a dictionary of metadata:

```
>>> meta
OrderedDict([('META1', 'a'), ('META2', 6)])
```

The second is a dictionary of all the tables in the file:

```
>>> tables['SN']
<Table rows=2 names=('A', 'B', 'C')>
array([(1, 2.0, 'x'), (4, 5.0, 'y')],
      dtype=[('A', '<i8'), ('B', '<f8'), ('C', 'S1')])
```

If the file had an ‘NVAR’ keyword rather than ‘NVAR\_SN’, for example:

```
NVAR: 3
VARNAMES: A B C
SN: 1 2.0 x
SN: 4 5.0 y
SN: 5 8.2 z
```

it can be read by supplying a default table name:

```
>>> meta, tables = read_snana_ascii(f, default_tablename='SN')
```

## sncosmo.read\_snana\_fits

`sncosmo.read_snana_fits(head_file, phot_file, snids=None, n=None)`

Read the SNANA FITS format: two FITS files jointly representing metadata and photometry for a set of SNe.

### Parameters

**head\_file** [str] Filename of “HEAD” (“header”) FITS file.

**phot\_file** [str] Filename of “PHOT” (“photometry”) FITS file.

**snids** [list of str, optional] If given, only return the single entry with the matching SNIDs.

**n** [int] If given, only return the first **n** entries.

### Returns

**sne** [list of [Table](#)] Each item in the list is an astropy Table instance.

### Notes

If `head_file` contains a column ‘SNID’ containing strings, leading and trailing whitespace is stripped from all the values in that column.

If `phot_file` contains a column ‘FLT’, leading and trailing whitespace is stripped from all the values in that column.

### Examples

```
>>> sne = read_snana_fits('HEAD.fits', 'PHOT.fits')
>>> for sn in sne:
...     sn.meta # Metadata in an OrderedDict.
...     sn['MJD'] # MJD column
```

## sncosmo.read\_snana\_simlib

`sncosmo.read_snana_simlib(fname)`

Read an SNANA ‘simlib’ (simulation library) ascii file.

### Parameters

**fname** [str] Filename.

### Returns

**meta** [OrderedDict] Global meta data, not associated with any one LIBID. If DOCANA is present, it is stored in `meta['DOCUMENTATION']`.

**observation\_sets** [OrderedDict of [astropy.table.Table](#)] keys are LIBIDs, values are observation sets.

### Notes

- Anything following ‘#’ on each line is ignored as a comment.
- Keywords are space separated strings ending with a colon.
- If a line starts with ‘LIBID:’, the following lines are associated with the value of LIBID, until ‘END\_LIBID:’ is encountered.
- While reading a given LIBID, lines starting with ‘S’ or ‘T’ keywords are assumed to contain 12 space-separated values after the keyword. These are (1) MJD, (2) IDEXPT, (3) FLT, (4) CCD GAIN, (5) CCD NOISE, (6) SKYSIG, (7) PSF1, (8) PSF2, (9) PSF 2/1 RATIO, (10) ZPTAVG, (11) ZPTSIG, (12) MAG.
- Column (2) may represent co-added observations in a ‘111\*1’ format. In this case, the ‘IDEXPT’ column is split at the ‘\*’ into ‘IDEXPT’ and ‘NEXPOSE’
- Other lines inside a ‘LIBID:’/‘END\_LIBID:’ pair are treated as metadata for that LIBID.
- Any other keywords outside a ‘LIBID:’/‘END\_LIBID:’ pair are treated as global header keywords and are returned in the `meta` dictionary.

## Examples

```
>>> meta, obs_sets = read_snana_simlib('filename')
```

The second object is a dictionary of astropy Tables indexed by LIBID:

```
>>> obs_sets.keys()
[0, 1, 2, 3, 4]
```

Each table (libid) has metadata:

```
>>> obs_sets[0].meta
OrderedDict([('LIBID', 0), ('RA', 52.5), ('DECL', -27.5), ('NOBS', 161),
            ('MWEBV', 0.0), ('PIXSIZE', 0.27)])
```

Each table has the following columns:

```
>>> obs_sets[0].colnames
['SEARCH', 'MJD', 'IDEXPT', 'FLT', 'CCD_GAIN', 'CCD_NOISE', 'SKYSIG',
 'PSF1', 'PSF2', 'PSFRATIO', 'ZPTAVG', 'ZPTSIG', 'MAG']
```

## sncosmo.read\_griddata\_ascii

`sncosmo.read_griddata_ascii(name_or_obj)`

Read 2-d grid data from a text file.

Each line has values `x0 x1 y`. Space separated. `x1` values are only read for first `x0` value. Others are assumed to match.

### Parameters

**name\_or\_obj** [str or file-like object]

### Returns

**x0** [numpy.ndarray] 1-d array.

**x1** [numpy.ndarray] 1-d array.

**y** [numpy.ndarray] 2-d array of shape (len(x0), len(x1)).

## sncosmo.read\_griddata\_fits

`sncosmo.read_griddata_fits(name_or_obj, ext=0)`

Read a multi-dimensional grid of data from a FITS file, where the grid coordinates are encoded in the FITS-WCS header keywords.

### Parameters

**name\_or\_obj** [str or file-like object]

### Returns

**x0, x1, ...** [ndarray] 1-d arrays giving coordinates of grid. The number of these arrays will depend on the dimension of the data array. For example, if the data have two dimensions, a total of three arrays will be returned: **x0**, **x1**, **y**, with **x0** giving the coordinates of the first axis of **y**. If the data have three dimensions, a total of four arrays will be returned: **x0**, **x1**, **x2**, **y**, and so on with higher dimensions.

**y** [ndarray] n-d array of shape  $(\text{len}(\mathbf{x0}), \text{len}(\mathbf{x1}), \dots)$ . For three dimensions for example, the value at  $y[i, j, k]$  corresponds to coordinates  $(\mathbf{x0}[i], \mathbf{x1}[j], \mathbf{x2}[k])$ .

### sncosmo.write\_griddata\_ascii

**sncosmo.write\_griddata\_ascii**(*x0, x1, y, name\_or\_obj*)

Write 2-d grid data to a text file.

Each line has values **x0 x1 y**. Space separated.

#### Parameters

**x0** [numpy.ndarray] 1-d array.

**x1** [numpy.ndarray] 1-d array.

**y** [numpy.ndarray] 2-d array of shape  $(\text{len}(\mathbf{x0}), \text{len}(\mathbf{x1}))$ .

**name\_or\_obj** [str or file-like object] Filename to write to or open file.

### sncosmo.write\_griddata\_fits

**sncosmo.write\_griddata\_fits**(*x0, x1, y, name\_or\_obj*)

Write a 2-d grid of data to a FITS file

The grid coordinates are encoded in the FITS-WCS header keywords.

#### Parameters

**x0** [numpy.ndarray] 1-d array.

**x1** [numpy.ndarray] 1-d array.

**y** [numpy.ndarray] 2-d array of shape  $(\text{len}(\mathbf{x0}), \text{len}(\mathbf{x1}))$ .

**name\_or\_obj** [str or file-like object] Filename to write to or open file.

## 11.5.4 Spectra

---

<i>Spectrum</i> ([wave, flux, fluxerr, fluxcov, ...])	An observed spectrum of an object.
---	------------------------------------

---

### sncosmo.Spectrum

**class sncosmo.Spectrum**(*wave=None, flux=None, fluxerr=None, fluxcov=None, bin\_edges=None, wave\_unit=Unit('Angstrom'), unit=Unit('erg / (Angstrom cm2 s)'), time=None*)

An observed spectrum of an object.

This class is designed to represent an observed spectrum. An observed spectrum is a set of contiguous bins in wavelength (referred to as “spectral elements”) with associated flux measurements. We assume that each spectral element has uniform transmission in wavelength. A spectrum can optionally have associated uncertainties or covariance between the observed fluxes of the different spectral elements. A spectrum can also optionally have a time associated with it.

Internally, we store the edges of each of the spectral element wavelength bins. These are automatically recovered in the common case where a user has a list of central wavelengths for each bin. The wavelengths are stored internally in units of Angstroms. The flux is stored as a spectral flux density  $F_{\lambda}$  (units of  $\text{erg} / \text{s} / \text{cm}^2 / \text{Angstrom}$ ).

### Parameters

**wave** [list-like] Central wavelengths of each spectral element. This must be monotonically increasing. This is assumed to be in units of Angstroms unless `wave_unit` is specified.

**flux** [list-like] Observed fluxes for each spectral element. By default this is assumed to be a spectral flux density  $F_{\lambda}$  unless `unit` is explicitly specified.

**fluxerr** [list-like] Uncertainties on the observed fluxes for each spectral element.

**fluxcov** [two-dimensional `ndarray`] Covariance of the observed fluxes for each spectral element. Only one of `fluxerr` and `fluxcov` may be specified.

**bin\_edges** [list-like] Edges of each spectral element in wavelength. This should be a list that is length one longer than `flux`. Only one of `wave` and `bin_edges` may be specified.

**wave\_unit** [`Unit`] Wavelength unit. Default is Angstroms.

**unit** [`Unit`] Flux unit. Default is  $F_{\lambda}$  (erg / s / cm<sup>2</sup> / Angstrom).

**time** [float] The time associated with the spectrum. This is required if fitting a model to the spectrum.

`__init__` (*wave=None, flux=None, fluxerr=None, fluxcov=None, bin\_edges=None, wave\_unit=Unit('Angstrom'), unit=Unit('erg / (Angstrom cm2 s)'), time=None*)

### Methods

---

`__init__` ([*wave, flux, fluxerr, fluxcov, ...*])

<code>bandflux(band[, zp, zpsys])</code>	Perform synthetic photometry in a given bandpass.
<code>bandfluxcov(band[, zp, zpsys])</code>	Like <code>bandflux()</code> , but also returns model covariance on values.
<code>bandmag(band, magsys)</code>	Magnitude through the given bandpass(es), and for the given magnitude system(s).
<code>get_sampling_matrix()</code>	Build an appropriate sampling for the spectral elements.
<code>has_uncertainties()</code>	Check whether there is uncertainty information available.
<code>rebin([wave, bin_edges])</code>	Rebin the spectrum on a new wavelength grid.

### Attributes

<code>bin_ends</code>	Return the end of each bin.
<code>bin_starts</code>	Return the start of each bin.
<code>fluxcov</code>	Return the covariance matrix
<code>fluxerr</code>	Return the uncertainties on each flux bin
<code>wave</code>	Return the centers of each bin.

## 11.5.5 Fitting Photometric Data

*Estimate model parameters from photometric data*

<code>fit_lc</code> (data, model, vparam_names, bounds, ...)	Fit model parameters to data by minimizing $\chi^2$ .
<code>mcmc_lc</code> (data, model, vparam_names[, bounds, ...])	Run an MCMC chain to get model parameter samples.
<code>nest_lc</code> (data, model, vparam_names, bounds[, ...])	Run nested sampling algorithm to estimate model parameters and evidence.

### sncosmo.fit\_lc

```
sncosmo.fit_lc(data=None, model=None, vparam_names=[], bounds=None, spectra=None, method='minuit',
               guess_amplitude=True, guess_t0=True, guess_z=True, minsnr=5.0, modelcov=False,
               verbose=False, maxcall=10000, phase_range=None, wave_range=None, warn=True)
```

Fit model parameters to data by minimizing  $\chi^2$ .

This function defines a  $\chi^2$  to minimize, makes initial guesses for  $t_0$  and amplitude, then runs a minimizer.

#### Parameters

**data** [[Table](#) or [ndarray](#) or [dict](#)] Table of photometric data. Must include certain columns. See the “Photometric Data” section of the documentation for required columns.

**model** [[Model](#)] The model to fit.

**vparam\_names** [list] Model parameters to vary in the fit.

**bounds** [[dict](#), optional] Bounded range for each parameter. Keys should be parameter names, values are tuples. If a bound is not given for some parameter, the parameter is unbounded. The exception is **t0**: by default, the minimum bound is such that the latest phase of the model lines up with the earliest data point and the maximum bound is such that the earliest phase of the model lines up with the latest data point.

**spectra** [[Spectrum](#) or list of [Spectrum](#) objects] A list of spectra to include in the fit.

**guess\_amplitude** [bool, optional] Whether or not to guess the amplitude from the data. If false, the current model amplitude is taken as the initial value. Only has an effect when fitting amplitude. Default is True.

**guess\_t0** [bool, optional] Whether or not to guess  $t_0$ . Only has an effect when fitting  $t_0$ . Default is True.

**guess\_z** [bool, optional] Whether or not to guess  $z$  (redshift). Only has an effect when fitting redshift. Default is True.

**minsnr** [float, optional] When guessing amplitude and  $t_0$ , only use data with signal-to-noise ratio ( $\text{flux} / \text{fluxerr}$ ) greater than this value. Default is 5.

**method** [{‘minuit’}], optional] Minimization method to use. Currently there is only one choice.

**modelcov** [bool, optional] Include model covariance when calculating  $\chi^2$ . Default is False. If true, the fit is performed multiple times until convergence.

**phase\_range** [(float, float), optional] If given, discard data outside this range of phases. Note that **the definition of phase varies between models**: For example,  $\text{phase}=0$  refers to explosion time in some models and time of peak B band flux in others.

*New in version 1.5.0*

**wave\_range** [(float, float), optional] If given, discard data with bandpass effective wavelengths outside this range.

*New in version 1.5.0*

**verbose** [bool, optional] Print messages during fitting.

**warn** [bool, optional] Issue a warning when dropping bands outside the wavelength range of the model. Default is True.

*New in version 1.5.0*

## Returns

**res** [Result] The optimization result represented as a `Result` object, which is a `dict` subclass with attribute access. Therefore, `res.keys()` provides a list of the attributes. Attributes are:

- **success**: boolean describing whether fit succeeded.
- **message**: string with more information about exit status.
- **ncall**: number of function evaluations.
- **chisq**: minimum  $\chi^2$  value.
- **ndof**: number of degrees of freedom ( $\text{len}(\text{data}) - \text{len}(\text{vparam\_names})$ ).
- **param\_names**: same as `model.param_names`.
- **parameters**: 1-d `ndarray` of best-fit values (including fixed parameters) corresponding to `param_names`.
- **vparam\_names**: list of varied parameter names.
- **covariance**: 2-d `ndarray` of parameter covariance; indices correspond to order of `vparam_names`.
- **errors**: `OrderedDict` of varied parameter uncertainties. Corresponds to square root of diagonal entries in covariance matrix.
- **nfit**: number of times the fit was performed. Can be greater than one when model covariance, phase range or wavelength range is used. *New in version 1.5.0.*
- **data\_mask**: Boolean array the same length as data specifying whether each observation was used in the final fit. *New in version 1.5.0.*

**fitmodel** [[Model](#)] A copy of the model with parameters set to best-fit values.

## Notes

**t0 guess**: If `t0` is being fit and `guess_t0=True`, the function will guess the initial starting point for `t0` based on the data. The guess is made as follows:

- Evaluate the time and value of peak flux for the model in each band given the current model parameters.
- Determine the data point with maximum flux in each band, for points with signal-to-noise ratio  $> \text{minsnr}$  (default is 5). If no points meet this criteria, the band is ignored (for the purpose of guessing only).
- For each band, compare model's peak flux to the peak data point. Choose the band with the highest ratio of data / model.
- Set `t0` so that the model's time of peak in the chosen band corresponds to the peak data point in this band.



**amplitude guess:** If amplitude (assumed to be the first model parameter) is being fit and `guess_amplitude=True`, the function will guess the initial starting point for the amplitude based on the data.

**redshift guess:** If redshift ( $z$ ) is being fit and `guess_z=True`, the function will set the initial value of  $z$  to the average of the bounds on  $z$ .

## Examples

The `flatten_result` function can be used to make the result a dictionary suitable for appending as rows of a table:

```
>>> from astropy.table import Table
>>> table_rows = []
>>> for sn in sne:
...     res, fitmodel = sncosmo.fit_lc(
...         sn, model, ['t0', 'x0', 'x1', 'c'])
...     table_rows.append(flatten_result(res))
>>> t = Table(table_rows)
```

## sncosmo.mcmc\_lc

```
sncosmo.mcmc_lc(data, model, vparam_names, bounds=None, priors=None, guess_amplitude=True,
                guess_t0=True, guess_z=True, minsnr=5.0, modelcov=False, nwalkers=10, nburn=200,
                nsamples=1000, sampler='ensemble', thin=1, a=2.0, warn=True)
```

Run an MCMC chain to get model parameter samples.

This is a convenience function around `emcee.EnsembleSampler`. It defines the likelihood function and makes a heuristic guess at a good set of starting points for the walkers. It then runs the sampler, starting with a burn-in run.

If you're not getting good results, you might want to try increasing the burn-in, increasing the walkers, or specifying a better starting position. To get a better starting position, you could first run `fit_lc`, then run this function with all `guess_[name]` keyword arguments set to `False`, so that the current model parameters are used as the starting point.

### Parameters

**data** [`Table` or `ndarray` or `dict`] Table of photometric data. Must include certain columns. See the “Photometric Data” section of the documentation for required columns.

**model** [`Model`] The model to fit.

**vparam\_names** [iterable] Model parameters to vary.

**bounds** [`dict`, optional] Bounded range for each parameter. Keys should be parameter names, values are tuples. If a bound is not given for some parameter, the parameter is unbounded. The exception is `t0`: by default, the minimum bound is such that the latest phase of the model lines up with the earliest data point and the maximum bound is such that the earliest phase of the model lines up with the latest data point.

**priors** [`dict`, optional] Prior probability functions. Keys are parameter names, values are functions that return probability given the parameter value. The default prior is a flat distribution.

**guess\_amplitude** [bool, optional] Whether or not to guess the amplitude from the data. If false, the current model amplitude is taken as the initial value. Only has an effect when fitting amplitude. Default is `True`.

- guess\_t0** [bool, optional] Whether or not to guess t0. Only has an effect when fitting t0. Default is True.
- guess\_z** [bool, optional] Whether or not to guess z (redshift). Only has an effect when fitting redshift. Default is True.
- minsnr** [float, optional] When guessing amplitude and t0, only use data with signal-to-noise ratio (flux / fluxerr) greater than this value. Default is 5.
- modelcov** [bool, optional] Include model covariance when calculating chisq. Default is False.
- nwalkers** [int, optional] Number of walkers in the sampler.
- nburn** [int, optional] Number of samples in burn-in phase.
- nsamples** [int, optional] Number of samples in production run.
- sampler: str, optional** The kind of sampler to use. Currently only ‘ensemble’ for `emcee.EnsembleSampler` is supported.
- thin** [int, optional] Factor by which to thin samples in production run. Output samples array will have (nsamples/thin) samples.
- a** [float, optional] Proposal scale parameter passed to the sampler.
- warn** [bool, optional] Issue a warning when dropping bands outside the wavelength range of the model. Default is True.

*New in version 1.5.0*

## Returns

- res** [Result] Has the following attributes:
- **param\_names**: All parameter names of model, including fixed.
  - **parameters**: Model parameters, with varied parameters set to mean value in samples.
  - **vparam\_names**: Names of parameters varied. Order of parameters matches order of samples.
  - **samples**: 2-d array with shape (N, len(vparam\_names)). Order of parameters in each row matches order in `res.vparam_names`.
  - **covariance**: 2-d array giving covariance, measured from samples. Order corresponds to `res.vparam_names`.
  - **errors**: dictionary giving square root of diagonal of covariance matrix for varied parameters. Useful for `plot_lc`.
  - **mean\_acceptance\_fraction**: mean acceptance fraction for all walkers in the sampler.
  - **ndof**: Number of degrees of freedom (len(data) - len(vparam\_names)). *New in version 1.5.0.*
  - **data\_mask**: Boolean array the same length as data specifying whether each observation was used. *New in version 1.5.0.*
- est\_model** [[Model](#)] Copy of input model with varied parameters set to mean value in samples.

## sncosmo.nest\_lc

```
sncosmo.nest_lc(data, model, vparam_names, bounds, guess_amplitude_bound=False, minsnr=5.0,
                priors=None, ppfs=None, npoints=100, method='single', maxiter=None, maxcall=None,
                modelcov=False, rstate=None, verbose=False, warn=True, **kwargs)
```

Run nested sampling algorithm to estimate model parameters and evidence.

### Parameters

**data** [[Table](#) or [ndarray](#) or [dict](#)] Table of photometric data. Must include certain columns. See the “Photometric Data” section of the documentation for required columns.

**model** [[Model](#)] The model to fit.

**vparam\_names** [list] Model parameters to vary in the fit.

**bounds** [[dict](#)] Bounded range for each parameter. Bounds must be given for each parameter, with the exception of `t0`: by default, the minimum bound is such that the latest phase of the model lines up with the earliest data point and the maximum bound is such that the earliest phase of the model lines up with the latest data point.

**guess\_amplitude\_bound** [bool, optional] If true, bounds for the model’s amplitude parameter are determined automatically based on the data and do not need to be included in `bounds`. The lower limit is set to zero and the upper limit is 10 times the amplitude “guess” (which is based on the highest-flux data point in any band). Default is False.

**minsnr** [float, optional] Minimum signal-to-noise ratio of data points to use when guessing amplitude bound. Default is 5.

**priors** [[dict](#), optional] Prior probability distribution function for each parameter. The keys should be parameter names and the values should be callables that accept a float. If a parameter is not in the dictionary, the prior defaults to a flat distribution between the bounds.

**ppfs** [[dict](#), optional] Prior percent point function (inverse of the cumulative distribution function) for each parameter. If a parameter is in this dictionary, the ppf takes precedence over a prior pdf specified in `priors`.

**npoints** [int, optional] Number of active samples to use. Increasing this value increases the accuracy (due to denser sampling) and also the time to solution.

**method** [{‘classic’, ‘single’, ‘multi’}, optional] Method used to select new points. Choices are ‘classic’, single-ellipsoidal (‘single’), multi-ellipsoidal (‘multi’). Default is ‘single’.

**maxiter** [int, optional] Maximum number of iterations. Iteration may stop earlier if termination condition is reached. Default is no limit.

**maxcall** [int, optional] Maximum number of likelihood evaluations. Iteration may stop earlier if termination condition is reached. Default is no limit.

**modelcov** [bool, optional] Include model covariance when calculating chisq. Default is False.

**rstate** [[RandomState](#), optional] `RandomState` instance. If not given, the global random state of the `numpy.random` module will be used.

**verbose** [bool, optional] Print running evidence sum on a single line.

**warn** [bool, optional] Issue warning when dropping bands outside the model range. Default is True.

*New in version 1.5.0*

### Returns

**res** [[Result](#)] Attributes are:

- `niter`: total number of iterations
- `ncall`: total number of likelihood function calls
- `time`: time in seconds spent in iteration loop.
- `logz`: natural log of the Bayesian evidence  $Z$ .
- `logzerr`: estimate of uncertainty in `logz` (due to finite sampling)
- `h`: Bayesian information.
- `vparam_names`: list of parameter names varied.
- `samples`: 2-d `ndarray`, shape is (nsamples, nparameters). Each row is the parameter values for a single sample. For example, `samples[0, :]` is the parameter values for the first sample.
- `logprior`: 1-d `ndarray` (length=nsamples); log(prior volume) for each sample.
- `logl`: 1-d `ndarray` (length=nsamples); log(likelihood) for each sample.
- `weights`: 1-d `ndarray` (length=nsamples); Weight corresponding to each sample. The weight is proportional to the prior \* likelihood for the sample.
- `parameters`: 1-d `ndarray` of weighted-mean parameter values from samples (including fixed parameters). Order corresponds to `model.param_names`.
- `covariance`: 2-d `ndarray` of parameter covariance; indices correspond to order of `vparam_names`. Calculated from `samples` and `weights`.
- `errors`: `OrderedDict` of varied parameter uncertainties. Corresponds to square root of diagonal entries in covariance matrix.
- `ndof`: Number of degrees of freedom (`len(data) - len(vparam_names)`).
- `bounds`: Dictionary of bounds on varied parameters (including any automatically determined bounds).
- `data_mask`: Boolean array the same length as data specifying whether each observation was used. *New in version 1.5.0.*

**estimated\_model** [[Model](#)] A copy of the model with parameters set to the values in `res.parameters`.

#### Convenience functions

<code>select_data(data, index)</code>	Convenience function for indexing photometric data with covariance.
<code>chisq(data, model[, modelcov])</code>	Calculate chisq statistic for the model, given the data.
<code>flatten_result(res)</code>	Turn a result from <code>fit_lc</code> into a simple dictionary of key, value pairs.

## sncosmo.select\_data

sncosmo.select\_data(data, index)

Convenience function for indexing photometric data with covariance.

This is like data[index] on an astropy Table, but handles covariance columns correctly.

### Parameters

**data** [Table] Table of photometric data.

**index** [slice or array or int] Row selection to apply to table.

### Returns

Table

## Examples

We have a small table of photometry with a covariance column and we want to select some rows based on a mask:

```
>>> data = Table([[1., 2., 3.],
...               ['a', 'b', 'c'],
...               [[1.1, 1.2, 1.3],
...                [2.1, 2.2, 2.3],
...                [3.1, 3.2, 3.3]]],
...               names=['time', 'x', 'cov'])
>>> mask = np.array([True, True, False])
```

Selecting directly on the table, the covariance column is not sliced in each row: it has shape (2, 3) when it should be (2, 2):

```
>>> data[mask]
<Table length=2>
   time    x    cov [3]
float64 str1 float64
-----
   1.0     a 1.1 .. 1.3
   2.0     b 2.1 .. 2.3
```

Using select\_data solves this:

```
>>> sncosmo.select_data(data, mask)
<Table length=2>
   time    x    cov [2]
float64 str1 float64
-----
   1.0     a 1.1 .. 1.2
   2.0     b 2.1 .. 2.2
```

## sncosmo.chisq

`sncosmo.chisq(data, model, modelcov=False)`

Calculate chisq statistic for the model, given the data.

### Parameters

**model** [*Model*]

**data** [*Table* or *ndarray* or *dict*] Table of photometric data. Must include certain columns. See the “Photometric Data” section of the documentation for required columns.

**modelcov** [bool] Include model covariance? Calls `model.bandfluxcov` method instead of `model.bandflux`. The source in the model must therefore implement covariance.

### Returns

**chisq** [float]

## sncosmo.flatten\_result

`sncosmo.flatten_result(res)`

Turn a result from `fit_lc` into a simple dictionary of key, value pairs.

Useful when saving results to a text file table, where structures like a covariance matrix cannot be easily written to a single table row.

### Parameters

**res** [*Result*] Result object from `fit_lc`.

### Returns

**flatres** [*Result*] Flattened result. Keys are all strings, values are one of: float, int, string), suitable for saving to a text file.

## 11.5.6 Plotting

*Convenience functions for quick standard plots (requires matplotlib)*

---

<code>plot_lc([data, model, bands, zp, zpsys, ...])</code>	Plot light curve data or model light curves.
--	--

---

## sncosmo.plot\_lc

`sncosmo.plot_lc(data=None, model=None, bands=None, zp=25.0, zpsys='ab', pulls=True, xfigsize=None, yfigsize=None, figtext=None, model_label=None, errors=None, ncol=2, figtextsize=1.0, show_model_params=True, tighten_ylim=False, color=None, cmap=None, cmap_lims=(3000.0, 10000.0), fill_data_marker=None, fname=None, fill_percentiles=None, **kwargs)`

Plot light curve data or model light curves.

### Parameters

**data** [*astropy Table* or similar, optional] Table of photometric data. Must include certain column names. See the “Photometric Data” section of the documentation for required columns.

**model** [*Model* or list thereof, optional] If given, model light curve is plotted. If a string, the corresponding model is fetched from the registry. If a list or tuple of *Model*, multiple models

are plotted.

**model\_label** [str or list, optional] If given, model(s) will be labeled in a legend in the upper left subplot. Must be same length as model.

**errors** [dict, optional] Uncertainty on model parameters. If given, along with exactly one model, uncertainty will be displayed with model parameters at the top of the figure.

**bands** [list, optional] List of Bandpasses, or names thereof, to plot.

**zp** [float, optional] Zeropoint to normalize the flux in the plot (for the purpose of plotting all observations on a common flux scale). Default is 25.

**zpsys** [str, optional] Zeropoint system to normalize the flux in the plot (for the purpose of plotting all observations on a common flux scale). Default is 'ab'.

**pulls** [bool, optional] If True (and if model and data are given), plot pulls. Pulls are the deviation of the data from the model divided by the data uncertainty. Default is True.

**figtext** [str, optional] Text to add to top of figure. If a list of strings, each item is placed in a separate "column". Use newline separators for multiple lines.

**ncol** [int, optional] Number of columns of axes. Default is 2.

**xfigsize, yfigsize** [float, optional] figure size in inches in x or y. Specify one or the other, not both. Default is to set axes panel size to 3.0 x 2.25 inches.

**figtextsize** [float, optional] Space to reserve at top of figure for figtext (if not None). Default is 1 inch.

**show\_model\_params** [bool, optional] If there is exactly one model plotted, the parameters of the model are added to **figtext** by default (as two additional columns) so that they are printed at the top of the figure. Set this to False to disable this behavior.

**tighten\_ylim** [bool, optional] If true, tighten the y limits so that the model is visible (if any models are plotted).

**color** [str or mpl\_color, optional] Color of data and model lines in each band. Can be any type of color that matplotlib understands. If None (default) a colormap will be used to choose a color for each band according to its central wavelength.

**cmap** [Colormap, optional] A matplotlib colormap to use, if color is None. If both color and cmap are None, a default colormap will be used.

**cmap\_lims** [(float, float), optional] The wavelength limits for the colormap, in Angstroms. Default is (3000., 10000.), meaning that a bandpass with a central wavelength of 3000 Angstroms will be assigned a color at the low end of the colormap and a bandpass with a central wavelength of 10000 will be assigned a color at the high end of the colormap.

**fill\_data\_marker** [array\_like, optional] Array of booleans indicating whether to plot a filled or unfilled marker for each data point. Default is all filled markers.

**fname** [str, optional] Filename to pass to savefig. If None (default), figure is returned.

**fill\_percentiles** [(float, float, float), optional] When multiple models are given, the percentiles for a light curve confidence interval. The upper and lower percentiles define a fill between region, and the middle percentile defines a line that will be plotted over the fill between region.

**kwargs** [optional] Any additional keyword args are passed to savefig. Popular options include dpi, format, transparent. See matplotlib docs for full list.

## Returns

**fig** [matplotlib Figure] Only returned if `fname` is `None`. Display to screen with `plt.show()` or save with `fig.savefig(filename)`. When creating many figures, be sure to close with `plt.close(fig)`.

## Examples

```
>>> import sncosmo
>>> import matplotlib.pyplot as plt
```

Load some example data:

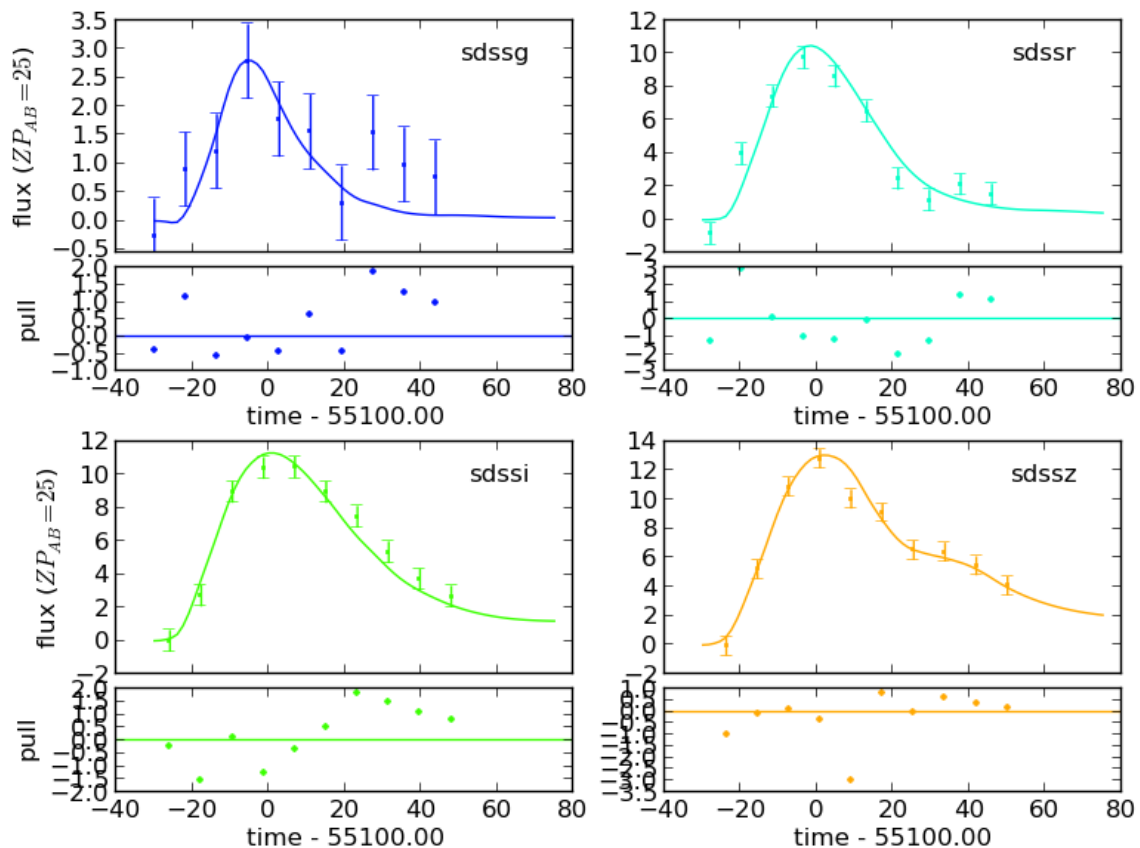
```
>>> data = sncosmo.load_example_data()
```

Plot the data, displaying to the screen:

```
>>> fig = plot_lc(data)
>>> plt.show()
```

Plot a model along with the data:

```
>>> model = sncosmo.Model('salt2')
>>> model.set(z=0.5, c=0.2, t0=55100., x0=1.547e-5)
>>> sncosmo.plot_lc(data, model=model)
```



Plot just the model, for selected bands:



```
>>> sncosmo.plot_lc(model=model,
...                 bands=['sdssg', 'sdssr'])
```

Plot figures on a multipage pdf:

```
>>> from matplotlib.backends.backend_pdf import PdfPages
>>> pp = PdfPages('output.pdf')
```

```
>>> # Do the following as many times as you like:
>>> sncosmo.plot_lc(data, fname=pp, format='pdf')
```

```
>>> # Don't forget to close at the end:
>>> pp.close()
```

## 11.5.7 Simulation

<code>zdist(zmin, zmax[, time, area, ratefunc, ...])</code>	Generate a distribution of redshifts.
<code>realize_lcs(observations, model, params[, ...])</code>	Realize data for a set of SNe given a set of observations.

### sncosmo.zdist

`sncosmo.zdist(zmin, zmax, time=365.25, area=1.0, ratefunc=<function <lambda>>, cosmo=FlatLambdaCDM( $H_0=70$  km / (Mpc s),  $Om_0=0.3$ ,  $Tcmb_0=0$  K,  $N_{eff}=3.04$ ,  $m_{nu}=None$ ,  $Ob_0=None$ ))`

Generate a distribution of redshifts.

Generates the correct redshift distribution and number of SNe, given the input volumetric SN rate, the cosmology, and the observed area and time.

#### Parameters

**zmin, zmax** [float] Minimum and maximum redshift.

**time** [float, optional] Time in days (default is 1 year).

**area** [float, optional] Area in square degrees (default is 1 square degree). **time** and **area** are only used to determine the total number of SNe to generate.

**ratefunc** [callable] A callable that accepts a single float (redshift) and returns the comoving volumetric rate at each redshift in units of  $\text{yr}^{-1} \text{Mpc}^{-3}$ . The default is a function that returns  $1.e-4$ .

**cosmo** [`Cosmology`, optional] Cosmology used to determine volume. The default is a Flat-LambdaCDM cosmology with  $Om_0=0.3$ ,  $H_0=70.0$ .

## Examples

Loop over the generator:

```
>>> for z in zdlist(0.0, 0.25):
...     print(z)
...
0.151285827576
0.204078030595
0.201009196731
0.181635472172
0.17896188781
0.226561237264
0.192747368762
```

This tells us that in one observer-frame year, over 1 square degree, 7 SNe occurred at redshifts below 0.35 (given the default volumetric SN rate of  $10^{-4}$  SNe  $\text{yr}^{-1} \text{Mpc}^{-3}$ ). The exact number is drawn from a Poisson distribution.

Generate the full list of redshifts immediately:

```
>>> zlist = list(zdlist(0., 0.25))
```

Define a custom volumetric rate:

```
>>> def snrate(z):
...     return 0.5e-4 * (1. + z)
...
>>> zlist = list(zdlist(0., 0.25, ratefunc=snrate))
```

## sncosmo.realize\_lcs

`sncosmo.realize_lcs(observations, model, params, thresh=None, trim_observations=False, scatter=True)`

Realize data for a set of SNe given a set of observations.

### Parameters

**observations** [Table or ndarray] Table of observations. Must contain the following column names: band, time, zp, zpsys, gain, skynoise.

**model** [`sncosmo.Model`] The model to use in the simulation.

**params** [list (or generator) of dict] List of parameters to feed to the model for realizing each light curve.

**thresh** [float, optional] If given, light curves are skipped (not returned) if none of the data points have signal-to-noise greater than **thresh**.

**trim\_observations** [bool, optional] If True, only observations with times between `model.mintime()` and `model.maxtime()` are included in result table for each SN. Default is False.

**scatter** [bool, optional] If True, the flux value of the realized data is calculated by adding a random number drawn from a Normal Distribution with a standard deviation equal to the `fluxerror` of the observation to the `bandflux` value of the observation calculated from `model`. Default is True.

### Returns

**sne** [list of [Table](#)] Table of realized data for each item in **params**.

## Notes

**skynoise** is the image background contribution to the flux measurement error (in units corresponding to the specified zeropoint and zeropoint system). To get the error on a given measurement, **skynoise** is added in quadrature to the photon noise from the source.

It is left up to the user to calculate **skynoise** as they see fit as the details depend on how photometry is done and possibly how the PSF is modeled. As a simple example, assuming a Gaussian PSF, and perfect PSF photometry, **skynoise** would be  $4 * \pi * \text{sigma\_PSF} * \text{sigma\_pixel}$  where **sigma\_PSF** is the standard deviation of the PSF in pixels and **sigma\_pixel** is the background noise in a single pixel in counts.

## 11.5.8 Registry

*Register and retrieve custom built-in sources, bandpasses, and magnitude systems*

<code>register(instance[, name, data_class, force])</code>	Register a class instance.
<code>register_loader(data_class, name, func[, ...])</code>	Register a data reading function.
<code>get_source(name[, version, copy])</code>	Retrieve a Source from the registry by name.
<code>get_bandpass(name, *args)</code>	Get a Bandpass from the registry by name.
<code>get_magsystem(name)</code>	Get a MagSystem from the registry by name.

### sncosmo.register

**sncosmo.register**(*instance, name=None, data\_class=None, force=False*)

Register a class instance.

#### Parameters

**instance** [object] The object to be registered.

**name** [str, optional] Identifier. If **None**, the name is taken from the **name** attribute of the instance, if it exists and is a string.

**data\_class** [classobj, optional] If given, the instance is registered as an instance of this class rather than the class of the instance itself. Use this for registering subclasses when you wish them to be accessible from their superclass.

**force** [bool, optional] Whether to override any existing instance of the same name. Note: this may not play well with versioned instances.

### sncosmo.register\_loader

**sncosmo.register\_loader**(*data\_class, name, func, args=None, version=None, meta=None, force=False*)

Register a data reading function.

#### Parameters

**data\_class** [classobj] The class of the object that the loader returns.

**name** [str] The data identifier.

**func** [callable] The function to read in the data. Must accept a name and version keyword argument.

**args** [list, optional] Arguments to pass to the function. Default is an empty list.

**version** [str, optional] Sub-version of name, if desired. Use formats such as '1', '1.0', '1.0.0', etc. Default is `None`.

**force** [bool, optional] Whether to override any existing function if already present.

**meta** [dict, optional] Metadata describing this loader. Default is an empty dictionary.

## sncosmo.get\_source

`sncosmo.get_source(name, version=None, copy=False)`

Retrieve a Source from the registry by name.

### Parameters

**name** [str] Name of source in the registry.

**version** [str, optional] Version identifier for sources with multiple versions. Default is `None` which corresponds to the latest, or only, version.

**copy** [bool, optional] If True and if **name** is already a Source instance, return a copy of it. (If **name** is a str a copy of the instance in the registry is always returned, regardless of the value of this parameter.) Default is False.

## sncosmo.get\_bandpass

`sncosmo.get_bandpass(name, *args)`

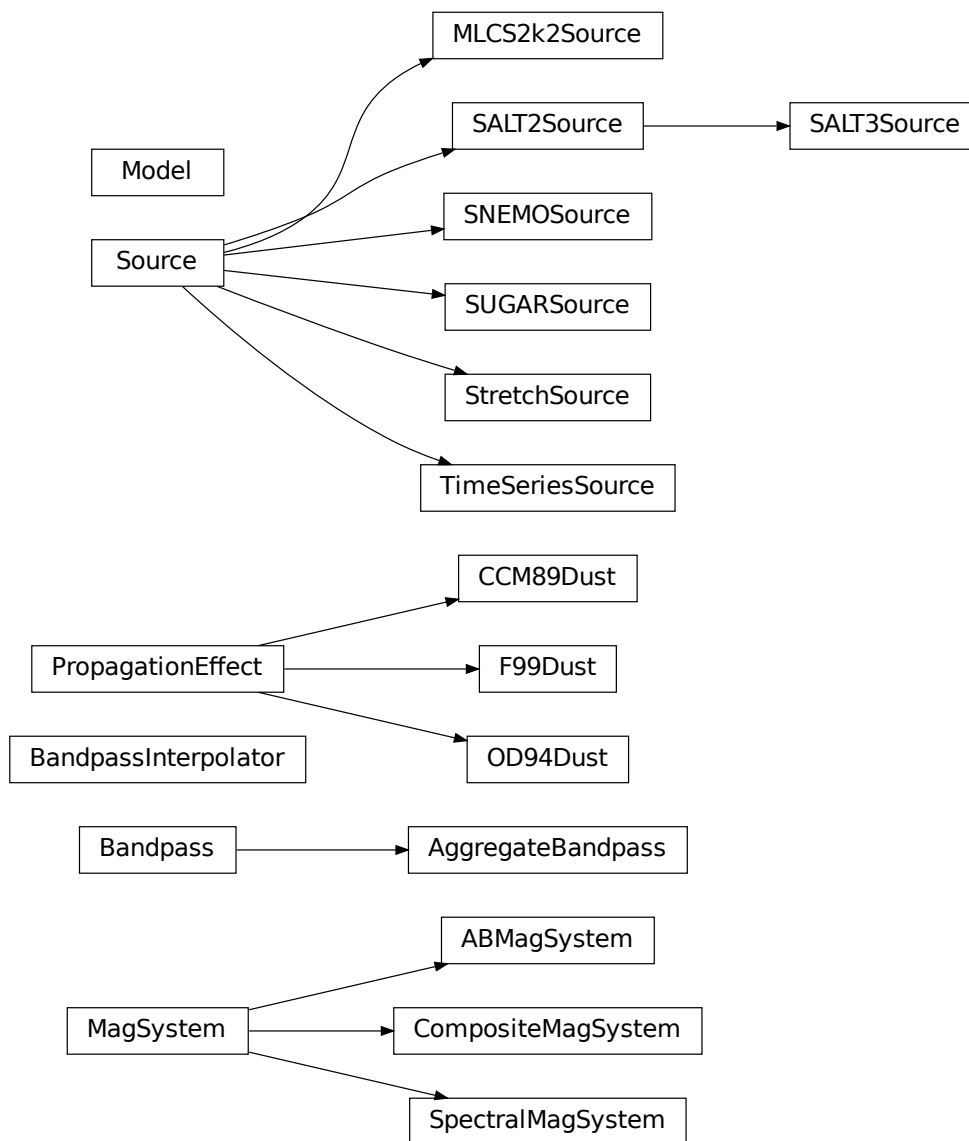
Get a Bandpass from the registry by name.

## sncosmo.get\_magsystem

`sncosmo.get_magsystem(name)`

Get a MagSystem from the registry by name.

### 11.5.9 Class Inheritance Diagrams



## 11.6 List of Built-in Sources

Name	Version	Type	Subclass	Reference	Website	Notes
'nugent-sn1a'	'1.2'	SN Ia	<a href="#">TimeSeriesSource</a>	[N02]		a
'nugent-sn91t'	'1.1'	SN Ia	<a href="#">TimeSeriesSource</a>	[S04]		a
'nugent-sn91bg'	'1.1'	SN Ia	<a href="#">TimeSeriesSource</a>	[N02]		a
'nugent-sn1bc'	'1.1'	SN Ib/c	<a href="#">TimeSeriesSource</a>	[L05]		a
'nugent-hyper'	'1.2'	SN Ib/c	<a href="#">TimeSeriesSource</a>	[L05]		a
'nugent-sn2p'	'1.2'	SN IIP	<a href="#">TimeSeriesSource</a>	[G99]		a
'nugent-sn2l'	'1.2'	SN IIL	<a href="#">TimeSeriesSource</a>	[G99]		a
'nugent-sn2n'	'2.1'	SN IIn	<a href="#">TimeSeriesSource</a>	[G99]		a
's11-2004hx'	'1.0'	SN IIL/P	<a href="#">TimeSeriesSource</a>	[S11]		b [1]
's11-2005lc'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>	[S11]		b [1]
's11-2005hl'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>	[S11]		b [1]
's11-2005hm'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>	[S11]		b [1]
's11-2005gi'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>	[S11]		b [1]
's11-2006fo'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>	[S11]		b [1]
's11-2006jo'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>	[S11]		b [1]
's11-2006jl'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>	[S11]		b [1]
'hsiao'	'1.0'	SN Ia	<a href="#">TimeSeriesSource</a>	[H07]		c [2]
'hsiao'	'2.0'	SN Ia	<a href="#">TimeSeriesSource</a>	[H07]		c [2]
'hsiao'	'3.0'	SN Ia	<a href="#">TimeSeriesSource</a>	[H07]		c [2]
'hsiao-subsampled'	'3.0'	SN Ia	<a href="#">TimeSeriesSource</a>	[H07]		c [2]
'salt2'	'2.0'	SN Ia	<a href="#">SALT2Source</a>	[G10]		d
'salt2'	'2.4'	SN Ia	<a href="#">SALT2Source</a>	[B14b]		d
'salt2-extended'	'1.0'	SN Ia	<a href="#">SALT2Source</a>		b	[3]
'salt2-extended'	'2.0'	SN Ia	<a href="#">SALT2Source</a>			
'salt3'	'1.0'	SN Ia	<a href="#">SALT3Source</a>		e	[4]
'salt2-extended-h17'	'1.0'	SN Ia	<a href="#">SALT2Source</a>	[H17]		f [5]
'snf-2011fe'	'1.0'	SN Ia	<a href="#">TimeSeriesSource</a>	[P13]		g
'snana-2004fe'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2004gq'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-sdss004012'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2006fo'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-sdss014475'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2006lc'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007ms'	'1.0'	SN II-pec	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-04d1la'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-04d4jv'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2004gv'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2006ep'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007y'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2004ib'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2005hm'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2006jo'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007nc'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2004hx'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2005gi'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2006gq'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2006kn'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]

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Name	Version	Type	Subclass	Reference	Website	Notes
'snana-2006jl'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2006iw'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2006kv'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2006ns'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007iz'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007nr'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007kw'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007ky'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007lj'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007lb'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007ll'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007nw'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007ld'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007md'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007lz'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007lx'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007og'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007ny'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007nv'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2007pg'	'1.0'	SN IIP	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2006ez'	'1.0'	SN IIn	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2006ix'	'1.0'	SN IIn	<a href="#">TimeSeriesSource</a>		h	[6]
'snana-2004fe'	'2.0'	SN Ic	<a href="#">TimeSeriesSource</a>			
'snana-2004gq'	'2.0'	SN Ic	<a href="#">TimeSeriesSource</a>			
'snana-sdss004012'	'2.0'	SN Ic	<a href="#">TimeSeriesSource</a>			
'snana-2006fo'	'2.0'	SN Ic	<a href="#">TimeSeriesSource</a>			
'snana-sdss014475'	'2.0'	SN Ic	<a href="#">TimeSeriesSource</a>			
'snana-2006lc'	'2.0'	SN Ic	<a href="#">TimeSeriesSource</a>			
'snana-2007ms'	'2.0'	SN II-pec	<a href="#">TimeSeriesSource</a>			
'snana-04d1la'	'2.0'	SN Ic	<a href="#">TimeSeriesSource</a>			
'snana-04d4jv'	'2.0'	SN Ic	<a href="#">TimeSeriesSource</a>			
'snana-2004gv'	'2.0'	SN Ib	<a href="#">TimeSeriesSource</a>			
'snana-2006ep'	'2.0'	SN Ib	<a href="#">TimeSeriesSource</a>			
'snana-2007y'	'2.0'	SN Ib	<a href="#">TimeSeriesSource</a>			
'snana-2004ib'	'2.0'	SN Ib	<a href="#">TimeSeriesSource</a>			
'snana-2005hm'	'2.0'	SN Ib	<a href="#">TimeSeriesSource</a>			
'snana-2006jo'	'2.0'	SN Ib	<a href="#">TimeSeriesSource</a>			
'snana-2007nc'	'2.0'	SN Ib	<a href="#">TimeSeriesSource</a>			
'snana-2004hx'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2005gi'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2006gq'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2006kn'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2006jl'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2006iw'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2006kv'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2006ns'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2007iz'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2007nr'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2007kw'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			

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Name	Version	Type	Subclass	Reference	Website	Notes
'snana-2007ky'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2007lj'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2007lb'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2007ll'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2007nw'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2007ld'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2007md'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2007lz'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2007lx'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2007og'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2007ny'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2007nv'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'snana-2007pg'	'2.0'	SN IIP	<a href="#">TimeSeriesSource</a>			
'v19-asassn14jb-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-asassn14jb'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-asassn15oz-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-asassn15oz'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-1987a-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-1987a'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-1993j-corr'	'1.0'	SN IIB	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-1993j'	'1.0'	SN IIB	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-1994i-corr'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-1994i'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-1998bw-corr'	'1.0'	SN Ic-BL	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-1998bw'	'1.0'	SN Ic-BL	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-1999dn-corr'	'1.0'	SN IIB	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-1999dn'	'1.0'	SN IIB	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-1999em-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-1999em'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2002ap-corr'	'1.0'	SN Ic-BL	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2002ap'	'1.0'	SN Ic-BL	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2004aw-corr'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2004aw'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2004et-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2004et'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2004fe-corr'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2004fe'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2004gq-corr'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2004gq'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2004gt-corr'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2004gt'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2004gv-corr'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2004gv'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2005bf-corr'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2005bf'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2005hg-corr'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2005hg'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2006t-corr'	'1.0'	SN IIB	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2006t'	'1.0'	SN IIB	<a href="#">TimeSeriesSource</a>		i	[7]

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Name	Version	Type	Subclass	Reference	Website	Notes
'v19-2006aa-corr'	'1.0'	SN II <sub>n</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2006aa'	'1.0'	SN II <sub>n</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2006aj-corr'	'1.0'	SN Ic-BL	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2006aj'	'1.0'	SN Ic-BL	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2006ep-corr'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2006ep'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2007y-corr'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2007y'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2007gr-corr'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2007gr'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2007od-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2007od'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2007pk-corr'	'1.0'	SN II <sub>n</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2007pk'	'1.0'	SN II <sub>n</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2007ru-corr'	'1.0'	SN Ic-BL	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2007ru'	'1.0'	SN Ic-BL	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2007uy-corr'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2007uy'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2008d-corr'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2008d'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2008aq-corr'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2008aq'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2008ax-corr'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2008ax'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2008bj-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2008bj'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2008bo-corr'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2008bo'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2008fq-corr'	'1.0'	SN II <sub>n</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2008fq'	'1.0'	SN II <sub>n</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2008in-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2008in'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2009n-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2009n'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2009bb-corr'	'1.0'	SN Ic-BL	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2009bb'	'1.0'	SN Ic-BL	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2009bw-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2009bw'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2009dd-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2009dd'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2009ib-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2009ib'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2009ip-corr'	'1.0'	SN II <sub>n</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2009ip'	'1.0'	SN II <sub>n</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2009iz-corr'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2009iz'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2009jf-corr'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2009jf'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2009kr-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]

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Name	Version	Type	Subclass	Reference	Website	Notes
'v19-2009kr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2010al-corr'	'1.0'	SN II <sub>n</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2010al'	'1.0'	SN II <sub>n</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2011bm-corr'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2011bm'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2011dh-corr'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2011dh'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2011ei-corr'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2011ei'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2011fu-corr'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2011fu'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2011hs-corr'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2011hs'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2011ht-corr'	'1.0'	SN II <sub>n</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2011ht'	'1.0'	SN II <sub>n</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2012a-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2012a'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2012ap-corr'	'1.0'	SN Ic-BL	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2012ap'	'1.0'	SN Ic-BL	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2012au-corr'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2012au'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2012aw-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2012aw'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2013ab-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2013ab'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2013am-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2013am'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2013by-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2013by'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2013df-corr'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2013df'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2013ej-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2013ej'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2013fs-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2013fs'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2013ge-corr'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2013ge'	'1.0'	SN Ic	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2014g-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2014g'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2016x-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2016x'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2016bkv-corr'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2016bkv'	'1.0'	SN II	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2016gkg-corr'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-2016gkg'	'1.0'	SN II <sub>b</sub>	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-iptf13bvn-corr'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'v19-iptf13bvn'	'1.0'	SN Ib	<a href="#">TimeSeriesSource</a>		i	[7]
'whalen-z15b'	'1.0'	PopIII	<a href="#">TimeSeriesSource</a>	[Whalen13]		[8]
'whalen-z15d'	'1.0'	PopIII	<a href="#">TimeSeriesSource</a>	[Whalen13]		[8]

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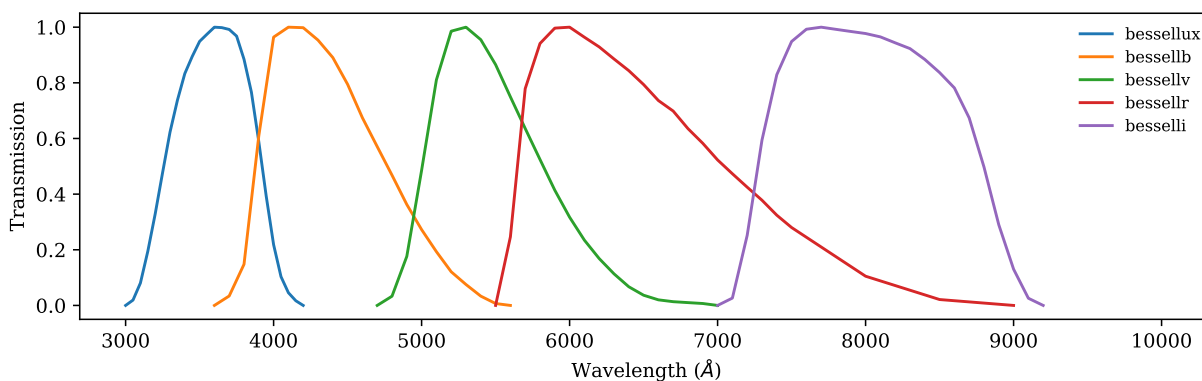
Table 53 – continued from previous page

Name	Version	Type	Subclass	Reference	Website	Notes
‘whalen-z15g’	‘1.0’	PopIII	<a href="#">TimeSeriesSource</a>	[Whalen13]		[8]
‘whalen-z25b’	‘1.0’	PopIII	<a href="#">TimeSeriesSource</a>	[Whalen13]		[8]
‘whalen-z25d’	‘1.0’	PopIII	<a href="#">TimeSeriesSource</a>	[Whalen13]		[8]
‘whalen-z25g’	‘1.0’	PopIII	<a href="#">TimeSeriesSource</a>	[Whalen13]		[8]
‘whalen-z40b’	‘1.0’	PopIII	<a href="#">TimeSeriesSource</a>	[Whalen13]		[8]
‘whalen-z40g’	‘1.0’	PopIII	<a href="#">TimeSeriesSource</a>	[Whalen13]		[8]
‘mlcs2k2’	‘1.0’	SN Ia	<a href="#">MLCS2k2Source</a>	[Jha07]		[9]
‘snemo2’	‘1.0’	SN Ia	<a href="#">SNEMOSource</a>	[Saunders18]		j
‘snemo7’	‘1.0’	SN Ia	<a href="#">SNEMOSource</a>	[Saunders18]		j
‘snemo15’	‘1.0’	SN Ia	<a href="#">SNEMOSource</a>	[Saunders18]		j
‘sugar’	‘1.0’	SN Ia	<a href="#">SUGARSource</a>	[Leget20]		k

## 11.7 List of Built-in Bandpasses

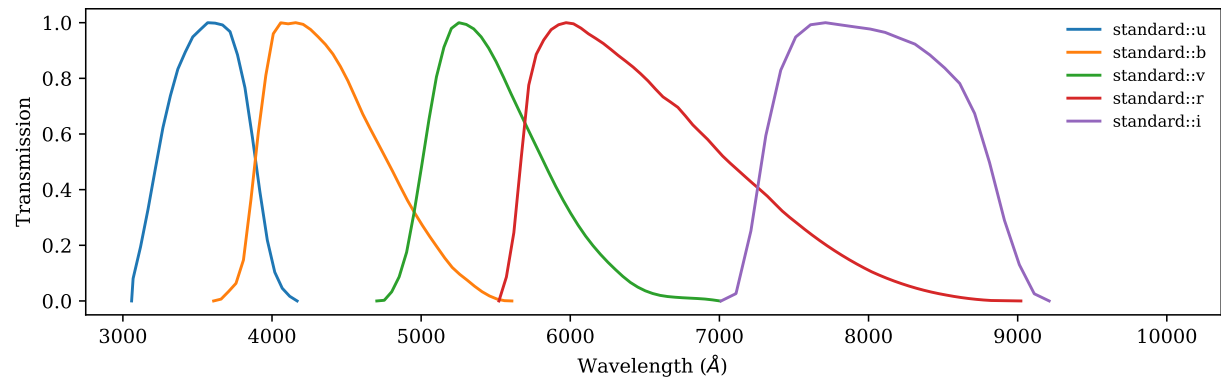
### 11.7.1 bessell

Name	Description	Data URL	Retrieved	Reference
‘bessellux’	Representation of Johnson-Cousins UBVRI system			[B90]
‘bessellb’	Representation of Johnson-Cousins UBVRI system			[B90]
‘bessellv’	Representation of Johnson-Cousins UBVRI system			[B90]
‘bessellr’	Representation of Johnson-Cousins UBVRI system			[B90]
‘besselli’	Representation of Johnson-Cousins UBVRI system			[B90]



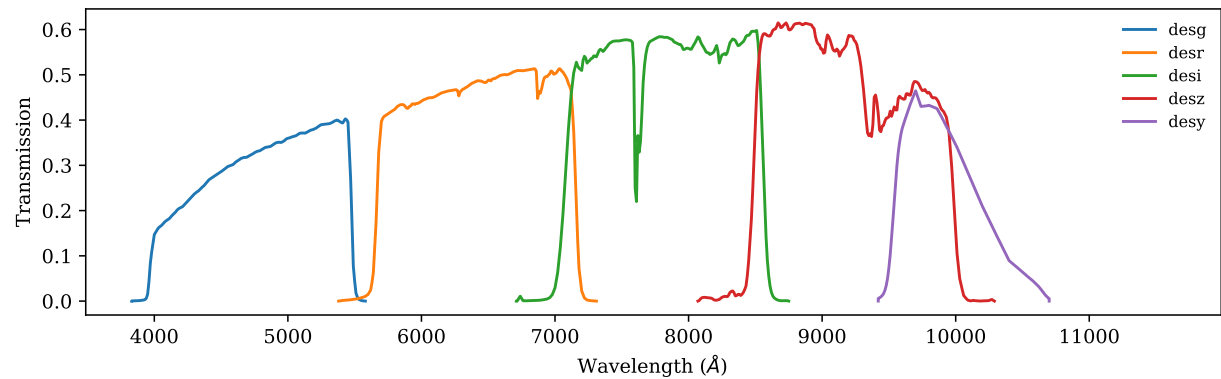
### 11.7.2 snls3-landolt

Name	Description	Data URL	Retrieved	Reference
‘standard::u’	Bessell bandpasses shifted as in JLA analysis	<a href="#">a</a>	13 February 2017	[B14a]
‘standard::b’	Bessell bandpasses shifted as in JLA analysis	<a href="#">a</a>	13 February 2017	[B14a]
‘standard::v’	Bessell bandpasses shifted as in JLA analysis	<a href="#">a</a>	13 February 2017	[B14a]
‘standard::r’	Bessell bandpasses shifted as in JLA analysis	<a href="#">a</a>	13 February 2017	[B14a]
‘standard::i’	Bessell bandpasses shifted as in JLA analysis	<a href="#">a</a>	13 February 2017	[B14a]



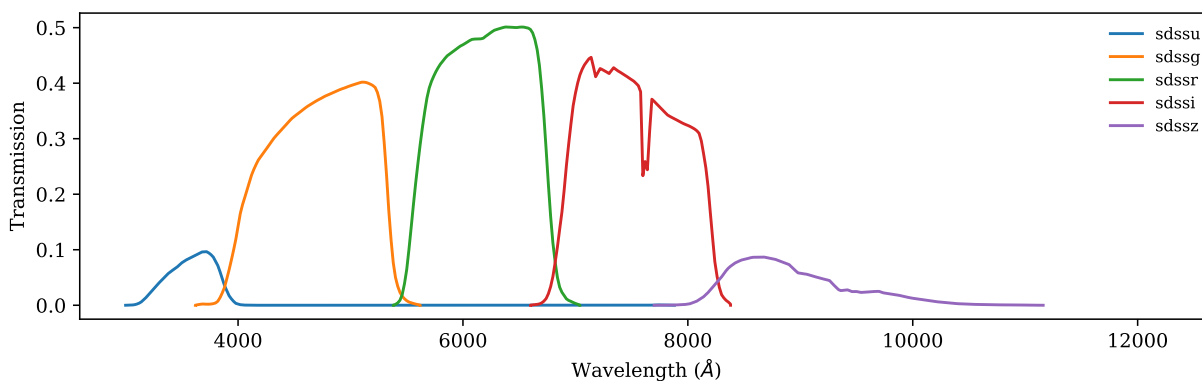
11.7.3 des

Name	Description	Data URL	Retrieved	Reference
'desg'	Dark Energy Camera grizy filter set at airmass 1.3		22 March 2013	
'desr'	Dark Energy Camera grizy filter set at airmass 1.3		22 March 2013	
'desi'	Dark Energy Camera grizy filter set at airmass 1.3		22 March 2013	
'desz'	Dark Energy Camera grizy filter set at airmass 1.3		22 March 2013	
'desy'	Dark Energy Camera grizy filter set at airmass 1.3		22 March 2013	



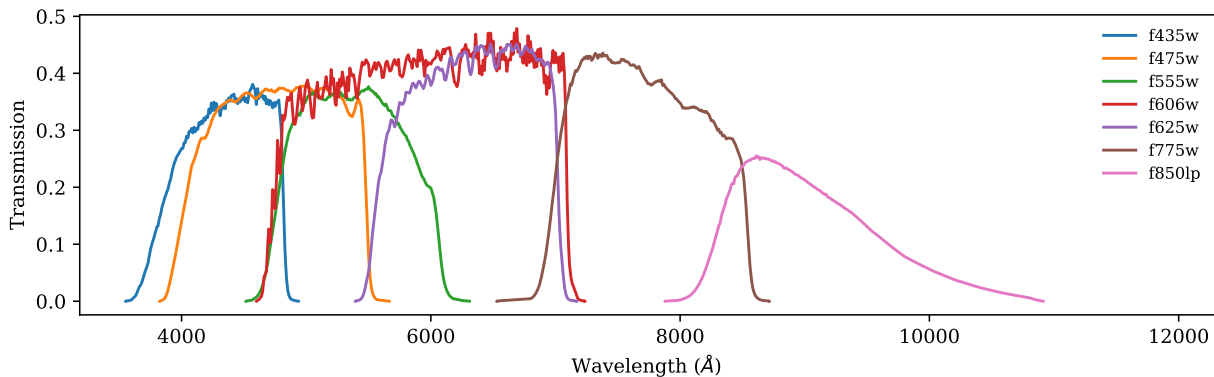
### 11.7.4 sdss

Name	Description	Data URL	Re-trieved	Refer-ence
'sdssu'	SDSS 2.5m imager at airmass 1.3 (including atmosphere), normalized			[D10]
'sdssg'	SDSS 2.5m imager at airmass 1.3 (including atmosphere), normalized			[D10]
'sdssr'	SDSS 2.5m imager at airmass 1.3 (including atmosphere), normalized			[D10]
'sdssi'	SDSS 2.5m imager at airmass 1.3 (including atmosphere), normalized			[D10]
'sdssz'	SDSS 2.5m imager at airmass 1.3 (including atmosphere), normalized			[D10]



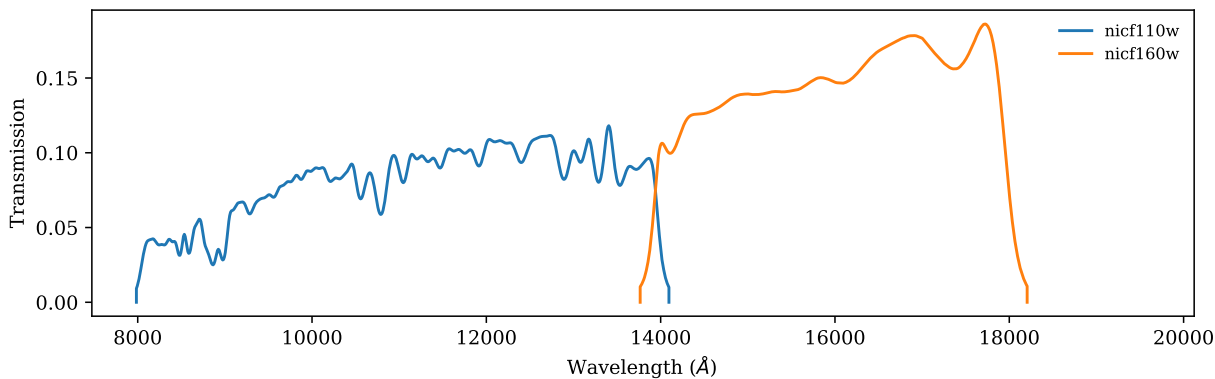
### 11.7.5 acs

Name	Description	Data URL	Retrieved	Reference
'f435w'	Hubble Space Telescope ACS WFC filters	<a href="#">b</a>	direct download	
'f475w'	Hubble Space Telescope ACS WFC filters	<a href="#">b</a>	direct download	
'f555w'	Hubble Space Telescope ACS WFC filters	<a href="#">b</a>	direct download	
'f606w'	Hubble Space Telescope ACS WFC filters	<a href="#">b</a>	direct download	
'f625w'	Hubble Space Telescope ACS WFC filters	<a href="#">b</a>	direct download	
'f775w'	Hubble Space Telescope ACS WFC filters	<a href="#">b</a>	direct download	
'f850lp'	Hubble Space Telescope ACS WFC filters	<a href="#">b</a>	direct download	



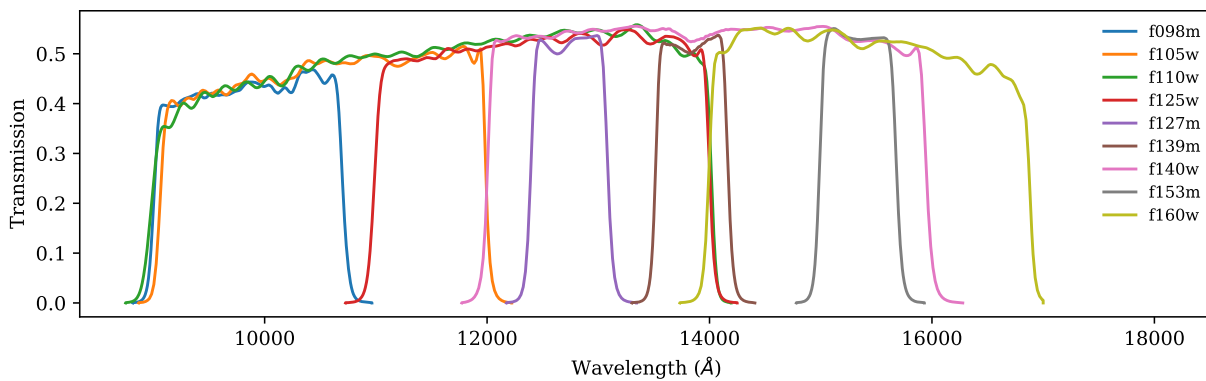
### 11.7.6 nicmos-nic2

Name	Description	Data URL	Retrieved	Reference
'nicf110w'	Hubble Space Telescope NICMOS2 filters	<a href="#">c</a>	05 Aug 2014	
'nicf160w'	Hubble Space Telescope NICMOS2 filters	<a href="#">c</a>	05 Aug 2014	



### 11.7.7 wfc3-ir

Name	Description	Data URL	Retrieved	Reference
'f098m'	Hubble Space Telescope WFC3 IR filters	<a href="#">d</a>	direct download	
'f105w'	Hubble Space Telescope WFC3 IR filters	<a href="#">d</a>	direct download	
'f110w'	Hubble Space Telescope WFC3 IR filters	<a href="#">d</a>	direct download	
'f125w'	Hubble Space Telescope WFC3 IR filters	<a href="#">d</a>	direct download	
'f127m'	Hubble Space Telescope WFC3 IR filters	<a href="#">d</a>	direct download	
'f139m'	Hubble Space Telescope WFC3 IR filters	<a href="#">d</a>	direct download	
'f140w'	Hubble Space Telescope WFC3 IR filters	<a href="#">d</a>	direct download	
'f153m'	Hubble Space Telescope WFC3 IR filters	<a href="#">d</a>	direct download	
'f160w'	Hubble Space Telescope WFC3 IR filters	<a href="#">d</a>	direct download	



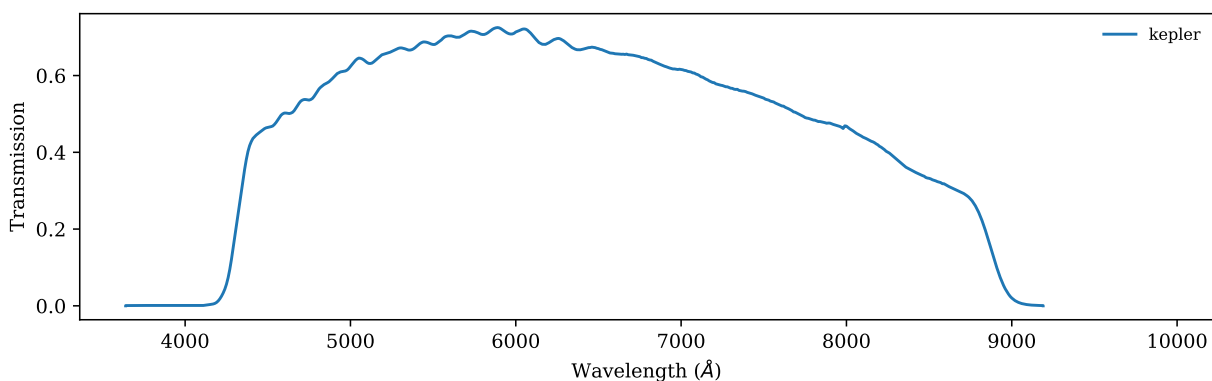
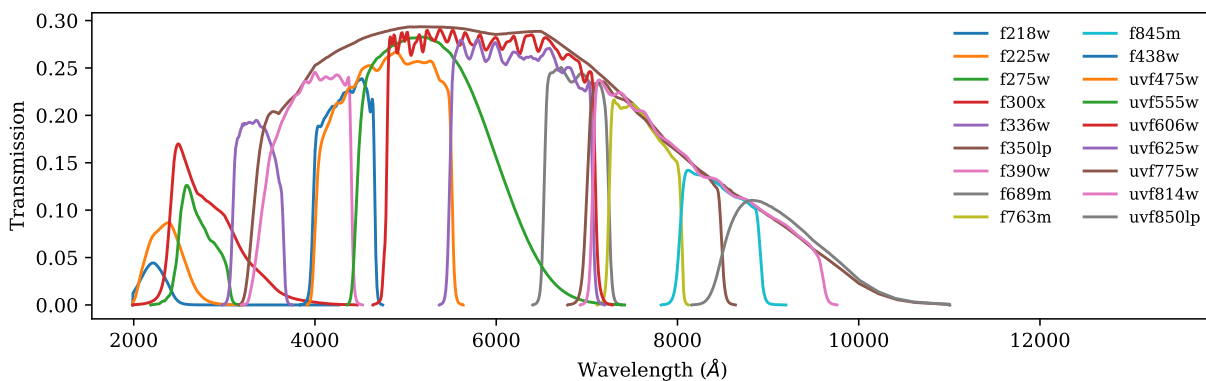
### 11.7.8 wfc3-uvis

Name	Description	Data URL	Retrieved	Reference
'f218w'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	
'f225w'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	
'f275w'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	
'f300x'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	
'f336w'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	
'f350lp'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	
'f390w'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	
'f689m'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	
'f763m'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	
'f845m'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	
'f438w'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	
'uvf475w'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	
'uvf555w'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	
'uvf606w'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	
'uvf625w'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	
'uvf775w'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	
'uvf814w'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	
'uvf850lp'	Hubble Space Telescope WFC3 UVIS filters (CCD 2)	d	direct load	

### 11.7.9 kepler

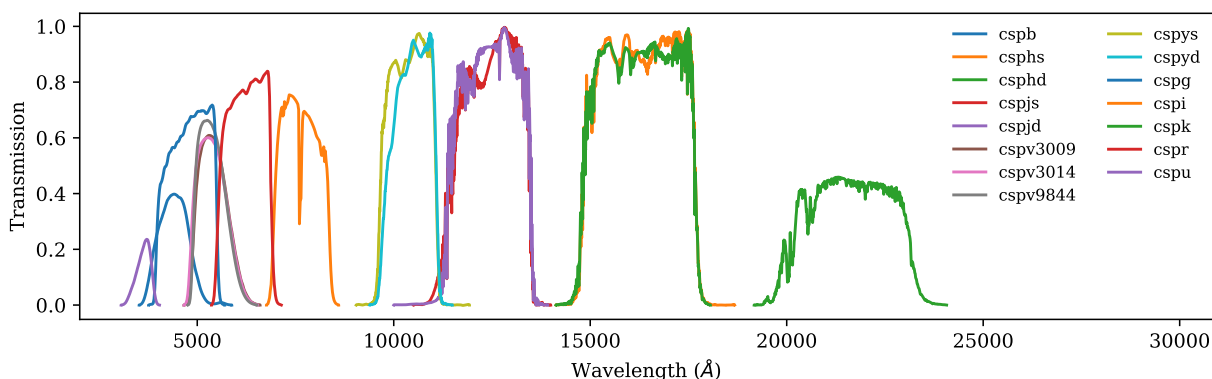
Name	Description	Data URL	Retrieved	Reference
'kepler'	Bandpass for the Kepler spacecraft	e	direct download	





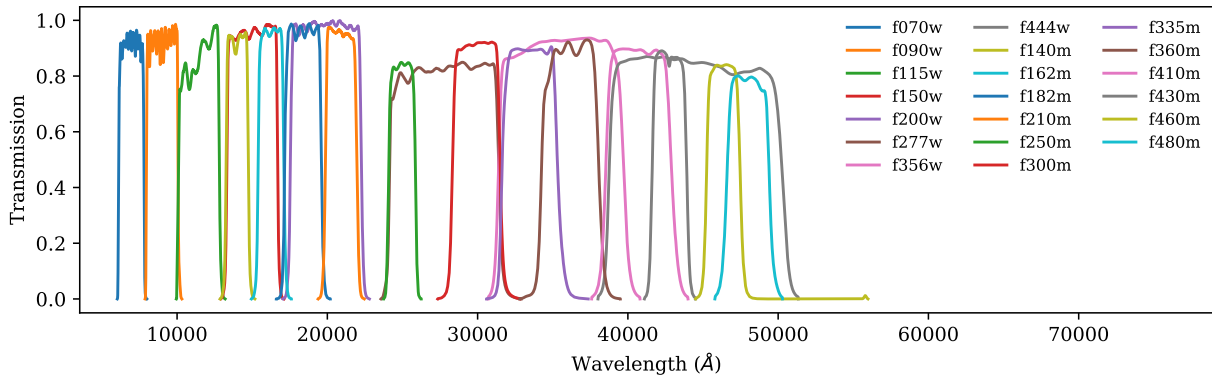
## 11.7.10 csp

Name	Description	Data URL	Re-trieved	Refer-ence
'cspb'	Carnegie Supernova Project filters (Swope+DuPont Telescopes) updated 6 Oct 2016	f	8 Feb 2017	
'csphs'	Carnegie Supernova Project filters (Swope+DuPont Telescopes) updated 6 Oct 2016	f	8 Feb 2017	
'csphd'	Carnegie Supernova Project filters (Swope+DuPont Telescopes) updated 6 Oct 2016	f	8 Feb 2017	
'cspjs'	Carnegie Supernova Project filters (Swope+DuPont Telescopes) updated 6 Oct 2016	f	8 Feb 2017	
'cspjd'	Carnegie Supernova Project filters (Swope+DuPont Telescopes) updated 6 Oct 2016	f	8 Feb 2017	
'cspv3009'	Carnegie Supernova Project filters (Swope+DuPont Telescopes) updated 6 Oct 2016	f	8 Feb 2017	
'cspv3014'	Carnegie Supernova Project filters (Swope+DuPont Telescopes) updated 6 Oct 2016	f	8 Feb 2017	
'cspv9844'	Carnegie Supernova Project filters (Swope+DuPont Telescopes) updated 6 Oct 2016	f	8 Feb 2017	
'cspys'	Carnegie Supernova Project filters (Swope+DuPont Telescopes) updated 6 Oct 2016	f	8 Feb 2017	
'cspyd'	Carnegie Supernova Project filters (Swope+DuPont Telescopes) updated 6 Oct 2016	f	8 Feb 2017	
'cspg'	Carnegie Supernova Project filters (Swope+DuPont Telescopes) updated 6 Oct 2016	f	8 Feb 2017	
'cspi'	Carnegie Supernova Project filters (Swope+DuPont Telescopes) updated 6 Oct 2016	f	8 Feb 2017	
'cspk'	Carnegie Supernova Project filters (Swope+DuPont Telescopes) updated 6 Oct 2016	f	8 Feb 2017	
'cspr'	Carnegie Supernova Project filters (Swope+DuPont Telescopes) updated 6 Oct 2016	f	8 Feb 2017	
'cspu'	Carnegie Supernova Project filters (Swope+DuPont Telescopes) updated 6 Oct 2016	f	8 Feb 2017	



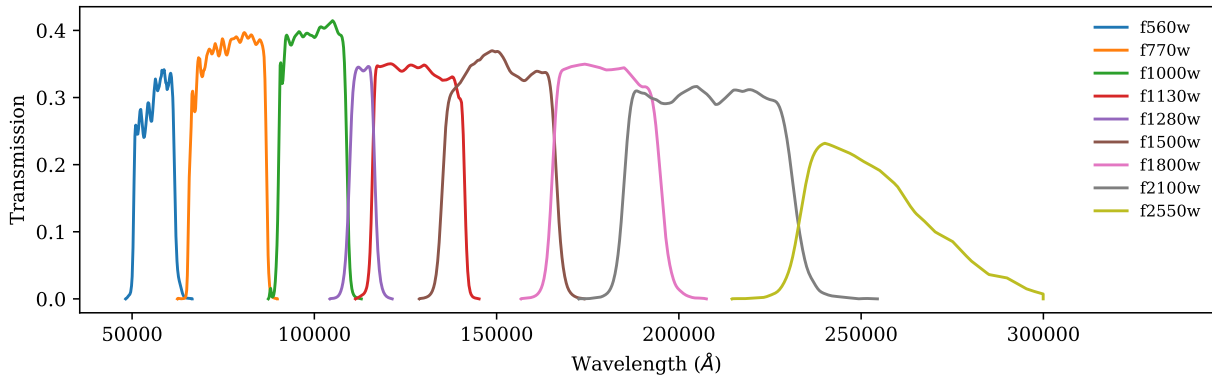
### 11.7.11 jwst-nircam

Name	Description	Data URL	Retrieved	Reference
'f070w'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f090w'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f115w'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f150w'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f200w'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f277w'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f356w'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f444w'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f140m'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f162m'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f182m'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f210m'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f250m'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f300m'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f335m'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f360m'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f410m'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f430m'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f460m'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	
'f480m'	James Webb Space Telescope NIRCAM Wide+Medium filters	<a href="#">g</a>	09 Sep 2014	



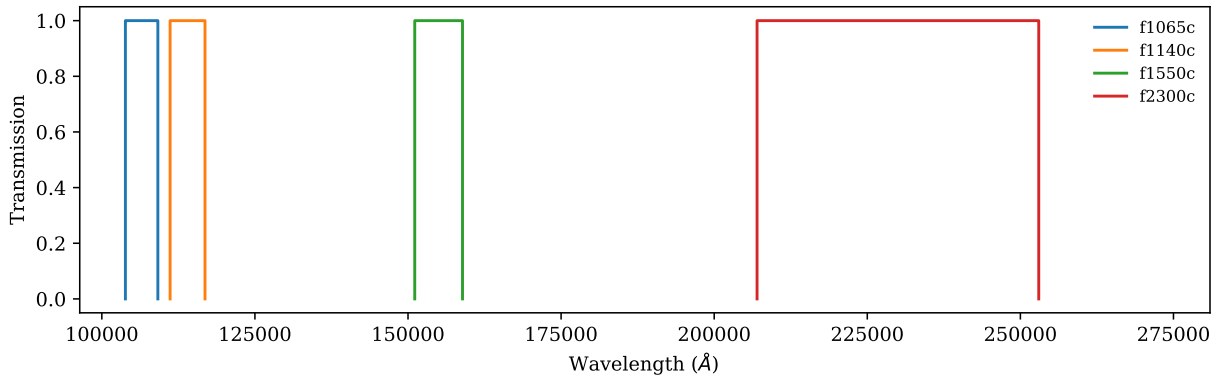
### 11.7.12 jwst-miri

Name	Description	Data URL	Retrieved	Reference
'f560w'	James Webb Space Telescope MIRI filters	<a href="#">h</a>	16 Feb 2017	
'f770w'	James Webb Space Telescope MIRI filters	<a href="#">h</a>	16 Feb 2017	
'f1000w'	James Webb Space Telescope MIRI filters	<a href="#">h</a>	16 Feb 2017	
'f1130w'	James Webb Space Telescope MIRI filters	<a href="#">h</a>	16 Feb 2017	
'f1280w'	James Webb Space Telescope MIRI filters	<a href="#">h</a>	16 Feb 2017	
'f1500w'	James Webb Space Telescope MIRI filters	<a href="#">h</a>	16 Feb 2017	
'f1800w'	James Webb Space Telescope MIRI filters	<a href="#">h</a>	16 Feb 2017	
'f2100w'	James Webb Space Telescope MIRI filters	<a href="#">h</a>	16 Feb 2017	
'f2550w'	James Webb Space Telescope MIRI filters	<a href="#">h</a>	16 Feb 2017	



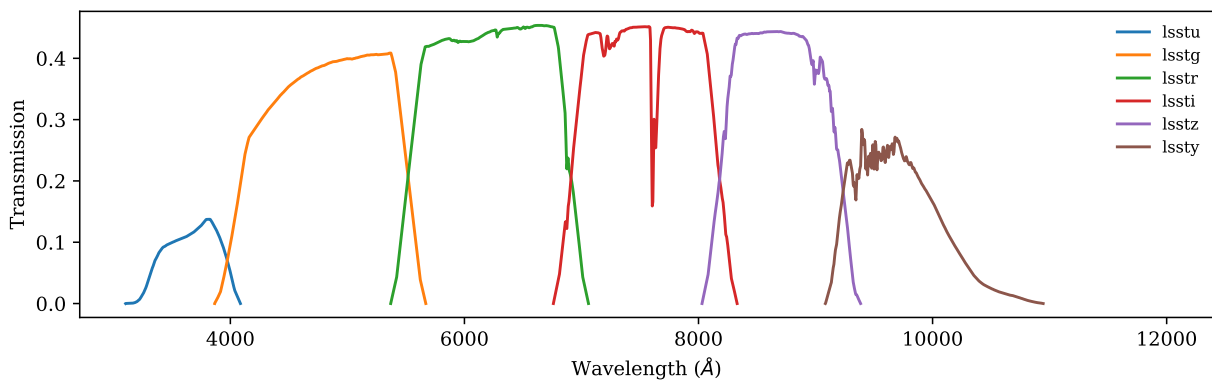
### 11.7.13 jwst-miri-tophat

Name	Description	Data URL	Retrieved	Reference
'f1065c'	James Webb Space Telescope MIRI filters (idealized tophat)	<a href="#">i</a>	09 Sep 2014	
'f1140c'	James Webb Space Telescope MIRI filters (idealized tophat)	<a href="#">i</a>	09 Sep 2014	
'f1550c'	James Webb Space Telescope MIRI filters (idealized tophat)	<a href="#">i</a>	09 Sep 2014	
'f2300c'	James Webb Space Telescope MIRI filters (idealized tophat)	<a href="#">i</a>	09 Sep 2014	



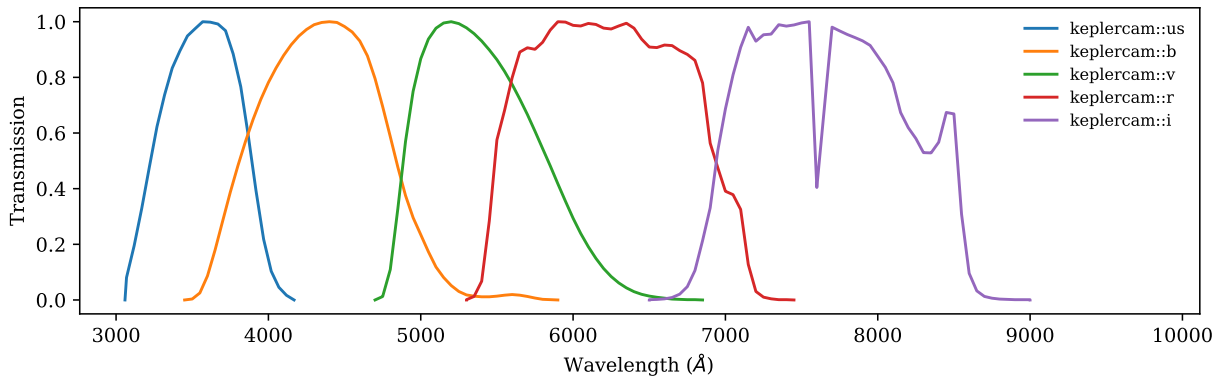
### 11.7.14 lsst

Name	Description	Data URL	Retrieved	Reference
'lsstu'	LSST baseline total throughputs, v1.1.	<a href="#">j</a>	16 Nov 2016	
'lsstg'	LSST baseline total throughputs, v1.1.	<a href="#">j</a>	16 Nov 2016	
'lsstr'	LSST baseline total throughputs, v1.1.	<a href="#">j</a>	16 Nov 2016	
'lssti'	LSST baseline total throughputs, v1.1.	<a href="#">j</a>	16 Nov 2016	
'lsstz'	LSST baseline total throughputs, v1.1.	<a href="#">j</a>	16 Nov 2016	
'lssty'	LSST baseline total throughputs, v1.1.	<a href="#">j</a>	16 Nov 2016	



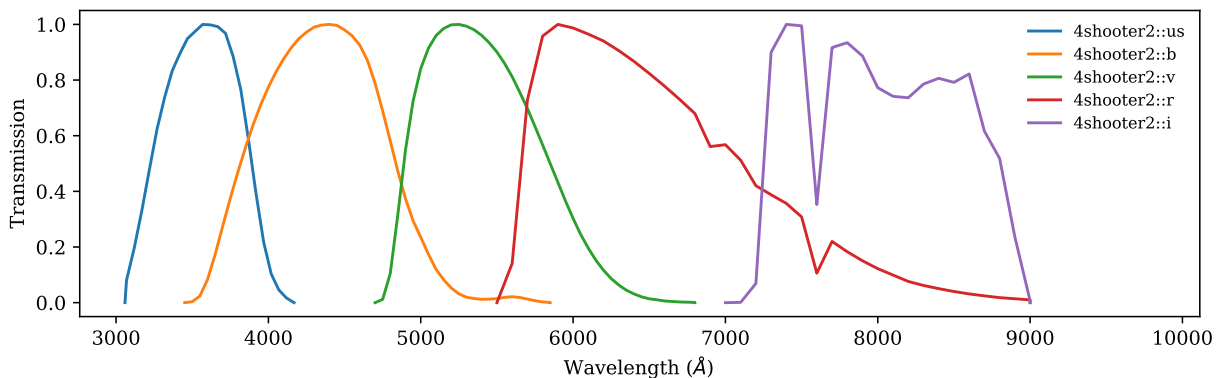
### 11.7.15 keplercam

Name	Description	Data URL	Retrieved	Reference
'keplercam::us'	Keplercam transmissions as used in JLA	<a href="#">a</a>	13 Feb 2017	
'keplercam::b'	Keplercam transmissions as used in JLA	<a href="#">a</a>	13 Feb 2017	
'keplercam::v'	Keplercam transmissions as used in JLA	<a href="#">a</a>	13 Feb 2017	
'keplercam::r'	Keplercam transmissions as used in JLA	<a href="#">a</a>	13 Feb 2017	
'keplercam::i'	Keplercam transmissions as used in JLA	<a href="#">a</a>	13 Feb 2017	



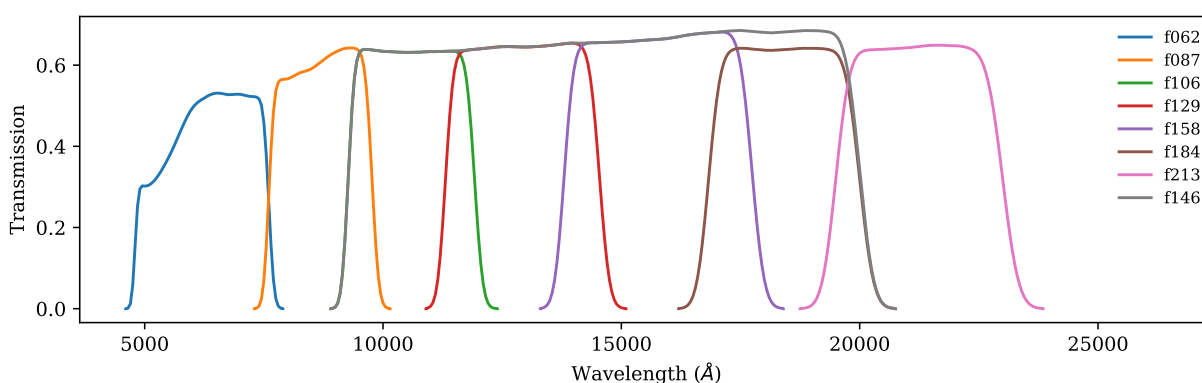
### 11.7.16 4shooter2

Name	Description	Data URL	Retrieved	Reference
'4shooter2::us'	4Shooter filters as used in JLA	<a href="#">a</a>	13 Feb 2017	
'4shooter2::b'	4Shooter filters as used in JLA	<a href="#">a</a>	13 Feb 2017	
'4shooter2::v'	4Shooter filters as used in JLA	<a href="#">a</a>	13 Feb 2017	
'4shooter2::r'	4Shooter filters as used in JLA	<a href="#">a</a>	13 Feb 2017	
'4shooter2::i'	4Shooter filters as used in JLA	<a href="#">a</a>	13 Feb 2017	



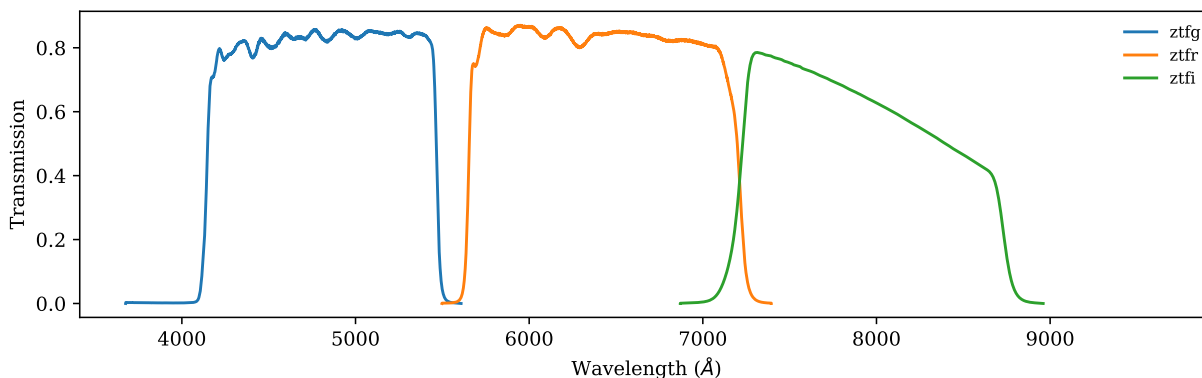
### 11.7.17 roman-wfi

Name	Description	Data URL	Retrieved	Reference
'f062'	Roman filters from Jeff Kruk: Roman_effarea_20201130.txt	<a href="#">k</a>	30 Nov 2020	
'f087'	Roman filters from Jeff Kruk: Roman_effarea_20201130.txt	<a href="#">k</a>	30 Nov 2020	
'f106'	Roman filters from Jeff Kruk: Roman_effarea_20201130.txt	<a href="#">k</a>	30 Nov 2020	
'f129'	Roman filters from Jeff Kruk: Roman_effarea_20201130.txt	<a href="#">k</a>	30 Nov 2020	
'f158'	Roman filters from Jeff Kruk: Roman_effarea_20201130.txt	<a href="#">k</a>	30 Nov 2020	
'f184'	Roman filters from Jeff Kruk: Roman_effarea_20201130.txt	<a href="#">k</a>	30 Nov 2020	
'f213'	Roman filters from Jeff Kruk: Roman_effarea_20201130.txt	<a href="#">k</a>	30 Nov 2020	
'f146'	Roman filters from Jeff Kruk: Roman_effarea_20201130.txt	<a href="#">k</a>	30 Nov 2020	



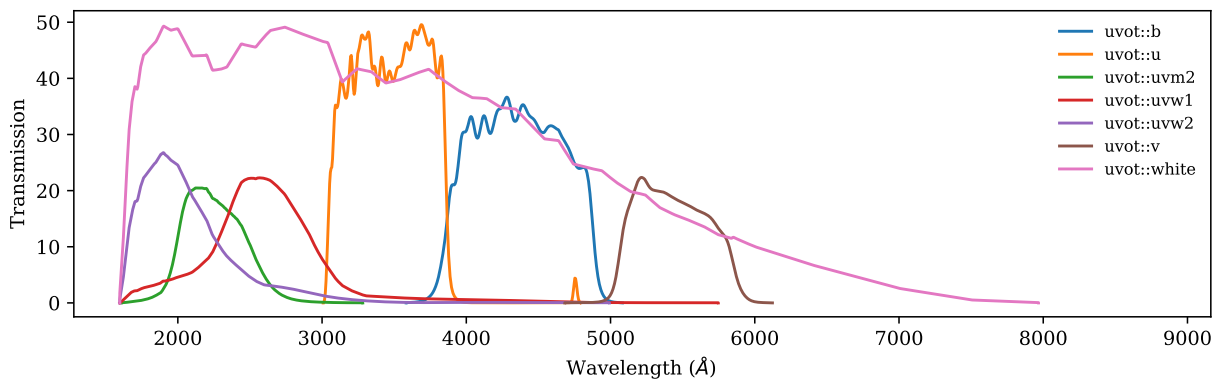
### 11.7.18 ztf

Name	Description	Data URL	Retrieved	Reference
'ztfg'	ZTF filters from Uli Feindt. No atmospheric correction.		7 Jun 2018	
'ztfr'	ZTF filters from Uli Feindt. No atmospheric correction.		7 Jun 2018	
'ztfi'	ZTF filters from Uli Feindt. No atmospheric correction.		7 Jun 2018	



### 11.7.19 swift-uvot

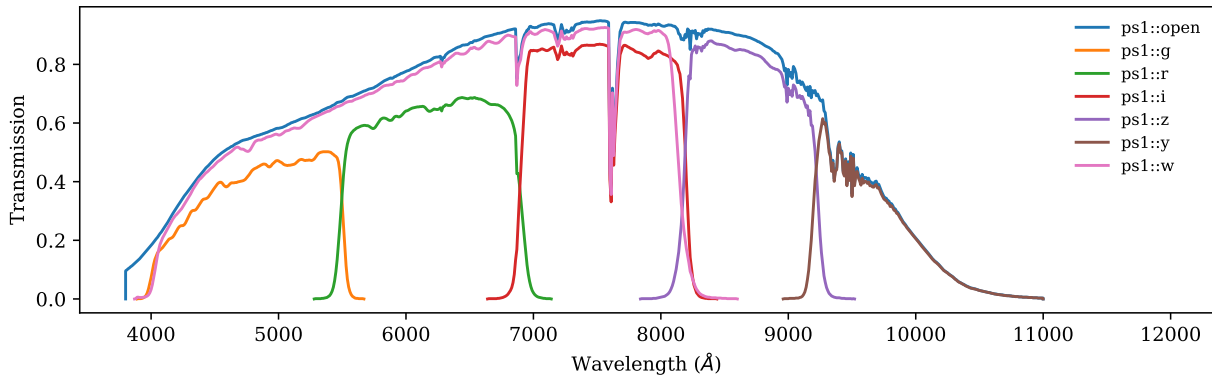
Name	Description	Data URL	Re-trieved	Refer-ence
'uvot::b'	Swift UVOT filters retrieved from the Spanish Virtual Observatory filter profile service.		19 May 2020	
'uvot::u'	Swift UVOT filters retrieved from the Spanish Virtual Observatory filter profile service.		19 May 2020	
'uvot::uvm2'	Swift UVOT filters retrieved from the Spanish Virtual Observatory filter profile service.		19 May 2020	
'uvot::uvw1'	Swift UVOT filters retrieved from the Spanish Virtual Observatory filter profile service.		19 May 2020	
'uvot::uvw2'	Swift UVOT filters retrieved from the Spanish Virtual Observatory filter profile service.		19 May 2020	
'uvot::v'	Swift UVOT filters retrieved from the Spanish Virtual Observatory filter profile service.		19 May 2020	
'uvot::white'	Swift UVOT filters retrieved from the Spanish Virtual Observatory filter profile service.		19 May 2020	



### 11.7.20 ps1

Name	Description	Data URL	Retrieved	Reference
'ps1::open'	Pan-STARRS1 filters at airmass 1.2	<a href="#">1</a>	17 Aug 2021	<a href="#">[T12]</a>
'ps1::g'	Pan-STARRS1 filters at airmass 1.2	<a href="#">1</a>	17 Aug 2021	<a href="#">[T12]</a>
'ps1::r'	Pan-STARRS1 filters at airmass 1.2	<a href="#">1</a>	17 Aug 2021	<a href="#">[T12]</a>
'ps1::i'	Pan-STARRS1 filters at airmass 1.2	<a href="#">1</a>	17 Aug 2021	<a href="#">[T12]</a>
'ps1::z'	Pan-STARRS1 filters at airmass 1.2	<a href="#">1</a>	17 Aug 2021	<a href="#">[T12]</a>
'ps1::y'	Pan-STARRS1 filters at airmass 1.2	<a href="#">1</a>	17 Aug 2021	<a href="#">[T12]</a>
'ps1::w'	Pan-STARRS1 filters at airmass 1.2	<a href="#">1</a>	17 Aug 2021	<a href="#">[T12]</a>



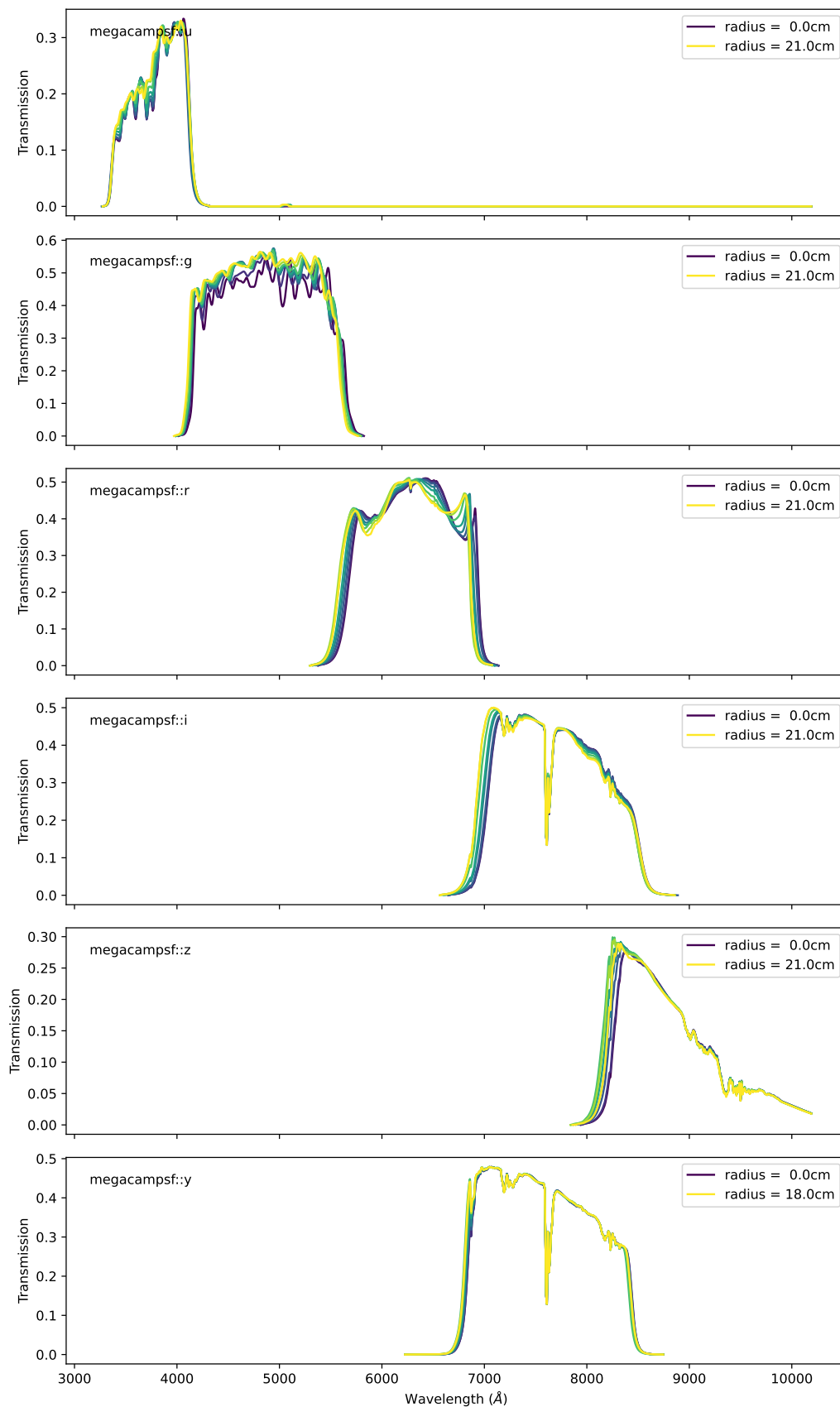


### 11.7.21 megacampsf

These are radially-variable bandpasses. To get a Bandpass at a given radius, use `band = sncosmo.get_bandpass('megacampsf::g', 13.0)`

## 11.8 List of Built-in Magnitude Systems

Name	Description	Subclass	Spectrum Source
'jla1'	JLA1 magnitude system based on BD+17 STIS v003 spectrum	<a href="#">CompositeMagSystem</a>	a
'ab'	Source of 3631 Jy has magnitude 0 in all bands	<a href="#">ABMagSystem</a>	
'vega'	Vega (alpha lyrae) has magnitude 0 in all bands.	<a href="#">SpectralMagSystem</a>	b
'bd17'	BD+17d4708 has magnitude 0 in all bands.	<a href="#">SpectralMagSystem</a>	b
'csp'	Carnegie Supernova Project magnitude system.	<a href="#">CompositeMagSystem</a>	c
'ab-b12'	Betoule et al (2012) calibration of SDSS system.	<a href="#">CompositeMagSystem</a>	a



**REFERENCE / API**



## 13.1 Version History

*Note:* SNCosmo uses [Semantic Versioning](#) for its version numbers. Specifically, this means that code written for sncosmo v1.0 will continue to work with any v1.x version. However, exact results may differ between versions in the 1.x series. (For example, due to changes in integration method.)

### 13.1.1 v2.6.0 (2021-09-09)

This release mostly involves modernizing the SNCosmo build system.

- Add Pan-STARRS1 bandpasses (#212)
- Added support for wheels which should now be automatically uploaded to PyPI for any new release (#304).
- Fixed the Zenodo integration. New SNCosmo releases should now automatically be archived to Zenodo.
- Moved citations to the new CITATION.cff format. GitHub and Zenodo will now provide BibTeX entries that can be used to cite SNCosmo (#302).
- Update to the emcee version 3 API. Now only compatible with emcee>=3.
- Migrate from Travis CI to GitHub Actions for continuous integration/tests (#293).
- Bugfixes:
  - Fixed the implementation of the SALT3 error model (#300).
  - Fixed numpy type deprecations.
  - Fixed the documentation for models (#299).

### 13.1.2 v2.5.0 (2021-04-20)

- Add SALT3 model from Kenworthy et al. (2021)
- Various documentation fixes

### 13.1.3 v2.4.0 (2021-03-05)

- Add SUGAR model from Leget et al. (2020)
- Add support for the iminuit 2.0 API (#291).
- Update tox to work with any version of Python 3.
- Bugfixes:
  - Fix flatten\_result bug due to API change (#285).

### 13.1.4 v2.3.0 (2020-11-16)

- Add Swift UVOT bandpasses.
- Bugfixes:
  - Fix segfaults in bicubic interpolation.

### 13.1.5 v2.2.0 (2020-10-23)

- Add core-collapse models from Vincenzi et al. (2019)
- New Spectrum class to handle processing and fitting spectral observations.
- Removed appveyor builds.
- Bugfixes:
  - Prevent segfaults in light curve fitting when the minuit fit fails.

### 13.1.6 v2.1.0 (2020-02-25)

- Add ZTF transmission functions
- Bugfixes
  - Corrected pyproject.toml; should help cases where the wrong numpy version was being installed.
  - Remove all references to the six package
  - Fix accidental mutation of bounds inputs in `fit_lc` and `mcmc_lc`.

### 13.1.7 v2.0.0 (2019-06-08)

This version is the same as v1.8, with the exception that Python 2 support has been removed, and deprecated functions and attributes have been removed. These were deprecated in v1.5.0 (released April 2017) or before.

On Python 2, pip should automatically install sncosmo v1.8 still. If not, specify `sncosmo<2.0.0`.

Minor changes:

- The `salt2-h17` source model has been renamed to `salt2-extended-h17` to make clearer its relation to `salt2-extended`. It is still available under the old name for backwards compatibility.

### 13.1.8 v1.8.2 (2019-06-08)

- Fix bug in download location of `snana-*` models latest versions, introduced in v1.8.0.

### 13.1.9 v1.8.1 (2019-06-08)

- Fix bug in download location of `salt2-extended` model latest version, introduced in v1.8.0.

### 13.1.10 v1.8.0 (2019-05-25)

- Add version 2.0 of many `snana-...` built-in core-collapse models, based on Pierel et al. 2018 (pull request 229).
- Bugfixes:
  - Fix compatibility with `scipy 1.3+` by removing outdated import statements (pull request 238).
  - Fix issue affecting optimization of models with free propagation effects (pull request 236).

### 13.1.11 v1.7.0 (2019-02-02)

- Add SNEMO2, SNEMO7, SNEMO15 source models from Saunders et al. (2018) to built-ins.

### 13.1.12 v1.6.0 (2018-04-27)

- Add Hounsell et al. (2017) SALT2 model to built-ins.
- Add `remote_timeout` configuration option.
- Build system: remove build-time dependency on astropy helpers.
- Bugfixes:
  - Correctly delete empty files created when a download fails.
  - Use pseudo-inverse when inverting covariance matrix for increased stability.
  - Fix an issue with pickling on Cython 0.26+.
  - Fixed problem where `data['fluxcov']` was unintentionally being modified in-place when passed to `fit_lc`.
  - Fixed problem where `'fluxcov'` not recognized as a valid name for covariance column in data in `fit_lc`.

### 13.1.13 v1.5.0 (2017-04-20)

This is a major new release. The highlight is really close compatibility of the SALT2 model and fitting procedure with `snfit`, the “official” SALT2 fitter.

- `SALT2Source`: Internal interpolation scheme of `SALT2Source` updated to match `snfit` implementation exactly. Test suite now tests against `snfit` implementation.
- `fit_lc()`:
  - Handling of model covariance updated to match that of `snfit`: model covariance is fixed for each fit and fit is repeated until convergence.

- New arguments `phase_range` and `wave_range`. If given, data outside this range will be discarded after an initial fit and additional fits will be performed until convergence. With `phase_range=(-15., 45.)` and `wave_range=(3000., 7000.)`, behavior approximates that of `snfit` with default arguments.
- Added support for covariance in photometric data measurements, and this covariance is used in `fit_lc()` if present. Covariance is stored as a `'fluxcov'` column in the table of measurements.
- Result includes two new attributes: `data_mask`, a boolean array indicating which rows in the input data were used in the final fit (since multiple fits might be performed), and `nfit`, the number of fits performed.
- New argument `warn` can be set to `False` to turn off warnings about dropping bands outside model wavelength range.
- `read_lc()`:
  - Added support for reading `snfit`-format “covmat” files into a table of photometry:

```
>>> data = read_lc('filename', format='salt2', read_covmat=True)
>>> data['Fluxcov'].shape == (len(data), len(data))
True
```
  - New keyword argument `expand_bands`. When `True`, the returned band column will contain `Bandpass` objects instead of strings. (Strings converted to `bandpass` objects using `sncosmo.get_bandpass()`.) This is particularly useful for position-dependent bandpasses in the `salt2` file format, such as `megacampsf`: `read_lc()` reads the position from the header and feeds the position to `get_bandpass()` to get a `Bandpass` object for the correct position.
- Built-in bandpasses and magnitude systems: Many new built-in bandpasses and magnitude systems.
- Configuration: The environment variable `SNCOSMO_DATA_DIR` can be used to set the path to the data directory. If set, it takes precedence over the `data_dir` variable in the configuration file (`$HOME/.astropy/config/sncosmo.cfg`).

### 13.1.14 v1.4.0 (2016-11-16)

- `SFD98Map` and `get_ebv_from_map` deprecated in favor of separate package `sfdmap` which has vastly improved performance (200x faster) for the typical case of scalar coordinates in ICRS frame.
- `animate_source()` deprecated. This is a “fun extra” that is difficult to test and no longer seems to work.
- Cython implementation of extinction functions has been factored out into a separate Python module called `extinction`, which is now a dependency.
- `Model.bandflux()` and `Source.bandflux()` now integrate on a fixed wavelength grid of 5 angstroms regardless of the wavelength grid of the bandpass. This will result in small differences in results from previous `sncosmo` versions.
- The internal (publicly undocumented) `Spectrum` class now acts more like `Model`; in particular, its `bandflux()` method now behaves the same way. As `Spectrum` backs `SpectralMagSystem`, this makes the integration of models and zeropoint spectra more consistent.
- Experimental (non-public) support for aliases for bandpasses, such as `'SDSS:g'` for `'sdssg'`.
- Sources now use cubic rather than quadratic spline interpolation internally.
- `Model.source_peakmag()` and `Model.set_source_peakmag()` added as convenience functions for `Model.source_peakmag()` and `Model.source.set_peakmag()` respectively.
- **[Bugfix]** Fixed missing import of `math` module in `mcmc_lc()` when using the `priors` keyword. [Backported to v1.3.1] [#143]



### 13.1.15 v1.3.0 (2016-06-30)

This is mostly a bugfix release, but it also **drops support for Python 2.6**. Python 2.7 is now the minimum supported Python version.

- Updates for compatibility with AstroPy 1.2.
- The registry now handles subclasses more robustly. For example, if `magsys` is an instance of `SpectralMagSystem`, the following used to fail:

```
sncosmo.register(magsys, 'name')
sncosmo.get_magsystem('name')
```

Now this works. [#132]

- **[Bugfix]** `SALT2Source` had a bug under Python 3 (only) yielding drastically wrong fluxes. Python 2 was not affected. [#138]

### 13.1.16 v1.2.0 (2015-12-01)

- **[API change]** Registry functions moved to the top-level namespace, as follows:
  - `sncosmo.registry.register()` -> `sncosmo.register()`
  - `sncosmo.registry.register_loader()` -> `sncosmo.register_loader()`
  - `sncosmo.registry.retrieve()` -> deprecated, use class-specific functions such as `sncosmo.get_bandpass()`.

The old import paths will still work for backwards compatibility.

- `nest_lc()` now uses the `nestle` module under the hood. A new keyword method is available which selects different sampling methods implemented by `nestle`. The new methods provide potential efficiency gains.
- The `MLCS2k2` model is now available as a built-in Source, with the name `'mlcs2k2'`.
- Bandpasses from the Carnegie Supernova Project added to built-ins.
- In `realize_lcs()`, a new `scatter` keyword makes adding noise optional.
- **[Bugfix]** Fix built-in Bessell bandpass definitions, which were wrong by a term proportional to inverse wavelength. This was due to misinterpretation of the transmission units. [backported to v1.1.1] [#111]

### 13.1.17 v1.1.0 (2015-08-12)

This is a mostly bugfix release with more solid support for Python 3.

- Added `Model.color()` method.
- Remove `loglmax` from result of `nest_lc()`, which was not officially documented or supported. Use `np.max(res.logl)` instead.
- Fixed bug that caused non-reproducible behavior in `nest_lc()` even when `numpy.random.seed()` was called directly beforehand. [#102]
- Fixed file I/O problems on Python 3 related to string encoding. [#83, #85]
- Fixed problem with SDSS bandpasses being stored as integers internally, preventing them from being used with models with dust. [#100, #101]
- Fixed problem where built-in source name and version strings were being dropped. [#82]

- Minor doc fixes.

### 13.1.18 v1.0.0 (2015-02-23)

- **[API change]** The API of `mcmc_lc` has changed significantly (the function was marked experimental in previous release).
- **[Deprecation]** In result of `fit_lc`, `res.cov_names` changed to `res.vparam_names`.
- **[Deprecation]** In result of `nest_lc`, `res.param_names` changed to `res.vparam_names`. This is for compatibility between the results of `fit_lc` and `nest_lc`. [#30]
- **[Deprecation]** Deprecate `flatten` keyword argument in `fit_lc()` in favor of explicit use of `flatten_result()` function.
- Many new built-in models.
- Many new built-in bandpasses.
- New remote data fetching system.
- SALT2 model covariance available via `Model.bandfluxcov()` method and `modelcov=True` keyword argument passed to `fit_lc`.
- New simulation function, `zdist`, generates a distribution of redshifts given a volumetric rate function and cosmology.
- New simulation function, `realize_lcs`, simulates light curve data given a model, parameters, and observations.
- Add color-related keyword arguments to `plot_lc()`.
- Add `tighten_ylim` keyword argument to `plot_lc()`.
- Add `chisq()` function and use internally in `fit_lc()`.
- Add `SFD98Map` class for dealing with SFD (1998) dust maps persistently so that the underlying FITS files are opened only once.
- Update `get_ebv_from_map()` to work with new `SkyCoord` class in `astropy.coordinates` available in `astropy` v0.3 onward. Previously, this function did not work with `astropy` v0.4.x (where older coordinates classes had been removed).
- Update to new configuration system available in `astropy` v0.4 onward. This makes this release incompatible with `astropy` versions less than 0.4.
- Now compatible with Python 3.
- Increased test coverage.
- Numerous minor bugfixes.

### 13.1.19 v0.4.0 (2014-03-26)

This is non-backwards-compatible release, due to changes in the way models are defined. These changes were made after feedback on the initial design.

The most major change is a new central class `Model` used throughout the package. A `Model` instance encompasses a `Source` and zero or more `PropagationEffect` instances. This is so that different source models (e.g., SALT2 or spectral time series models) can be combined with arbitrary dust models. The best way to think about this is `Source` and `PropagationEffect` define the rest-frame behavior of a SN and dust, and a `Model` puts these together to determine the observer-frame behavior.

- New classes:
  - `sncosmo.Model`: new main container class
  - `sncosmo.Source`: replaces existing `Model`
  - `sncosmo.TimeSeriesSource`: replaces existing `TimeSeriesModel`
  - `sncosmo.StretchSource`: replaces existing `StretchModel`
  - `sncosmo.SALT2Source`: replaces existing `SALT2Model`
  - `sncosmo.PropagationEffect`
  - `sncosmo.CCM89Dust`
  - `sncosmo.OD94Dust`
  - `sncosmo.F99Dust`
- New public functions:
  - `sncosmo.read_griddata_ascii`: Read file with `phase wave flux` rows
  - `sncosmo.read_griddata_fits`
  - `sncosmo.write_griddata_fits`
  - `sncosmo.nest_lc`: Nested sampling parameter estimation of SN model
  - `sncosmo.simulate_vol` (EXPERIMENTAL): simulation convenience function.
- Built-ins:
  - updated SALT2 model URLs
  - added SALT2 version 2.4 (Betoule et al 2014)
- Improvements to `sncosmo.plot_lc`: flexibility and layout
- Many bugfixes

### 13.1.20 v0.3.0 (2013-11-07)

This is a release with mostly bugfixes but a few new features, designed to be backwards compatible with v0.2.0 ahead of API changes coming in the next version.

- New Functions:
  - `sncosmo.get_ebv_from_map`: E(B-V) at given coordinates from SFD map.
  - `sncosmo.read_snana_ascii`: Read SNANA ascii format files.
  - `sncosmo.read_snana_fits`: Read SNANA FITS format files.
  - `sncosmo.read_snana_simlib`: Read SNANA ascii “SIMLIB” files.
- registry is now case-independent. All of the following now work:

```
sncosmo.get_magsystem('AB')
sncosmo.get_magsystem('Ab')
sncosmo.get_magsystem('ab')
```

- Photometric data can be unordered in time. Internally, the data are sorted before being used in fitting and typing.
- Numerous bugfixes.

### 13.1.21 v0.2.0 (2013-08-20)

- Added SN 2011fe Nearby Supernova Factory data to built-in models as '2011fe'
- Previously “experimental” functions now included:
  - `sncosmo.fit_lc` (previously `sncosmo.fit_model`)
  - `sncosmo.read_lc` (previously `sncosmo.readlc`)
  - `sncosmo.write_lc` (previously `sncosmo.writelc`)
  - `sncosmo.plot_lc` (previously `sncosmo.plotlc`)
- New functions:
  - `sncosmo.load_example_data`: Example photometric data.
  - `sncosmo.mcmc_lc`: Markov Chain Monte Carlo parameter estimation.
  - `sncosmo.animate_model`: Model animation using `matplotlib.animation`.
- Fitting: `sncosmo.fit_lc` now uses the `iminuit` package for minimization by default. This requires the `iminuit` package to be installed, but the old minimizer (from `scipy`) can still be used by setting the keyword `method='l-bfgs-b'`.
- Plotting: Ability to plot model synthetic photometry without observed data, using the syntax:

```
>>> sncosmo.plot_lc(model=model, bands=['band1', 'band2'])
```
- Photometric data format: Photometric data format is now more flexible, allowing various names for table columns.

### 13.1.22 v0.1.0 (2013-07-15)

Initial release.

## 13.2 About SNCosmo

### 13.2.1 Package Features

- **SN models:** Synthesize supernova spectra and photometry from SN models.
- **Fitting and sampling:** Functions for fitting and sampling SN model parameters given photometric light curve data.
- **I/O:** Convenience functions for reading and writing peculiar data formats used in other packages.
- **Built-in supernova models** such as SALT2, MLCS2k2, Hsiao, Nugent, PSNID, SNANA and Whalen models, as well as a variety of built-in bandpasses and magnitude systems.
- **Extensible:** New models, bandpasses, and magnitude systems can be defined, using an object-oriented interface.

### 13.2.2 The name SNCosmo

A natural choice, “snpy”, was already in use by the “SNooPy” package, so I tried to be a little more descriptive. The package is really specific to supernova *cosmology*, as it doesn’t cover other types of supernova science (radiative transfer simulations for instance). Hence “sncosmo”.

### 13.2.3 Contributors

SNCosmo was originally written by Kyle Barbary in 2012. Since then, over 20 people have contributed to its development. A full list of contributors can be found in the [CITATION.cff](#) file. Parsed versions of the author list, including BibTeX entries that can be used to cite SNCosmo, are available on [GitHub](#) and [Zenodo](#).

## 13.3 Contributing

### 13.3.1 Overview

SNCosmo follows the same general development workflow as *astropy* and many other open-source software projects. The [astropy development workflow](#) page documents the process in some detail. While you should indeed read that page, it can seem a bit overwhelming at first. So, we present here a rough outline of the process, and try to explain the reasoning behind it.

The process is centered around git and GitHub, so you need to know how to use basic git commands and also have a GitHub account. There is a “blessed” copy of the repository at <https://github.com/sncosmo/sncosmo>. Individual contributors make changes to their own copy (or “fork” or “clone” in git parlance) of the repository, e.g., <https://github.com/kbarbary/sncosmo>, then ask that their changes be merged into the “blessed” copy via a Pull Request (PR) on GitHub. A maintainer (currently Kyle) will review the changes in the PR, possibly ask for alterations, and then eventually merge the change.

This seems overly complex at first glance, but there are two main benefits to this process: (1) Anyone is free to try out any crazy change they want and share it with the world on their own GitHub account, without affecting the “blessed” repository, and (2) Any proposed changes are reviewed and discussed by at least one person (the maintainer) before being merged in.

### 13.3.2 Detailed steps

#### Do once:

1. Hit the “fork” button in the upper right hand corner of the <https://github.com/sncosmo/sncosmo> page. This creates a clone of the repository on your personal github account.
2. Get it onto your computer (replace username with your GitHub username):

```
git clone git@github.com:username/sncosmo.git
```

3. Add the “blessed” version as a remote:

```
git remote add upstream git@github.com:sncosmo/sncosmo.git
```

This will allow you to update your version to reflect new changes to the blessed repository that others have made).

4. Check that everything is OK:

```
$ git remote -v
origin    git@github.com:username/sncosmo.git (fetch)
origin    git@github.com:username/sncosmo.git (push)
upstream  git@github.com:sncosmo/sncosmo.git (fetch)
upstream  git@github.com:sncosmo/sncosmo.git (push)
```

You can call the remotes anything you want. “origin” and “upstream” have no intrinsic meaning for git; they’re just nicknames. The astropy documentation calls them “your-github-username” and “astropy” respectively.

5. Install the SNCosmo package in development mode. From the git directory:

```
pip install -e .
```

If you are only editing Python code, the latest code will be used when you import sncosmo in a Python interpreter for the first time. If you are editing any of the Cython code in SNCosmo (files with .c or .pyx extensions), then you will need to run this command again to compile that code for your changes to be picked up.

### Every time you want to make a contribution:

1. Ensure that the clone of the repository on your local machine is up-to-date with the latest upstream changes by doing `git fetch upstream`. This updates your local “remote tracking branch”, called `upstream/master`.
2. Create a “topic branch” for the change you want to make. If you plan to make enhancements to the simulation code, name the branch something like “simulation-enhancements”:

```
git branch simulation-enhancements upstream/master
```

(`upstream/master` is where the branch branches off from.)

3. Move to the branch you just created:

```
git checkout simulation-enhancements
```

4. *Make changes, ensure that they work, etc. Make commits as you go.*
5. Once you’re happy with the state of your branch, push it to your GitHub account for the world to see:

```
git push origin simulation-enhancements
```

6. Create a PR: Go to your copy on github (<https://github.com/username/sncosmo>) select the branch you just pushed in the upper left-ish of the page, and hit the green button next to it. (It has a mouse-over “compare, review, create a pull request”)

### What happens when the upstream branch is updated?

Suppose that you are following the above workflow: you created a topic branch `simulation-enhancements` and made a few commits on that branch. You now want to create a pull request, but there’s a problem: while you were working, more commits were added to the `upstream/master` branch on GitHub. The history of your branch has now diverged from the main development branch! What to do?

1. Fetch the changes made to the upstream branch on so that you can deal with the changes locally:

```
git fetch upstream
```

This will update your local branch `upstream/master` (and any other `upstream` branches) to the match the state of the upstream branch on GitHub. It doesn't do any merging or resolving, it just makes the new changes to `upstream/master` visible locally.

2. There are two options for this next step: `merge` or `rebase` with the latter being preferred for this purpose. Assuming you are on your branch `simulation-enhancements`, you *could* do `git merge upstream/master`. This would create a merge commit that merges the diverged histories back together. This works, but it can end up creating a confusing commit history, particularly if you repeat this process several times while working on your new branch. Instead, you can do:

```
git rebase upstream/master
```

This actually *rewrites* your commits to make it look like they started from where `upstream/master` now is, rather than where it was when you started work on your `simulation-enhancements` branch. Your branch will have the exact same contents as if you had used `git merge`, but the history will be different than it would have been if you had merged. In particular, there is no merge commit created, because the history has been rewritten so that your branch starts where `upstream/master` ends, and there is no divergent history to resolve. This means you can rebase again and again without creating a convoluted history full of merges back and forth between the branches.

## Trying out new ideas

git branches are the best way to try out new ideas for code modifications or additions. You don't even have to tell anyone about your bad ideas, since branches are local! They only become world visible when you push them to GitHub. If, after making several commits, you decide that your new branch `simulation-enhancements` sucks, you can just create a new branch starting from `upstream/master` again. If it is a really terrible idea you never want to see again, you can delete it by doing `git branch -D simulation-enhancements`.

Obviously this isn't a complete guide to git, but hopefully it jump-starts the git learning process.

### 13.3.3 Testing

SNCosmo uses `pytest` to check that all of the code is running as expected. When you add new functionality to SNCosmo, you should write a test for that functionality. All of the tests can be found in the `sncosmo/tests` directory.

When a new PR is created, the testsuite will be run automatically on a range of different machines and conditions using `tox`. You can run these same tests locally using `tox`. First, install `tox`:

```
pip install tox
```

From within the SNCosmo directory, run the test suite:

```
tox -e py3
```

The previous command will run the core test suite with the currently installed version of Python. You can run the full test suite with all of the optional dependencies by adding the `-alldeps` tag:

```
tox -e py3-alldeps
```

Running the tests with the `-cov` tag will generate a coverage report:

```
tox -e py3-cov
```

SNCosmo includes hundreds of builtin bandpasses and sources that are downloaded from external sites when they are loaded. `tox` can be used to check that all of these builtins are accessible with the following command:

```
tox -e builtins
```

tox can also be used to check the code style:

```
tox -e codestyle
```

or to build the documentation:

```
tox -e build_docs
```

tox uses virtual environments for testing which can be somewhat slow. You can alternatively run the test in your own Python environment. First, install all of the testing dependencies from the `test` section of `setup.cfg`. This can be done automatically when installing SNCosmo with the following command:

```
pip install -e .[test]
```

The tests can then be run with the following command:

```
pytest --pyargs sncosmo
```

### 13.3.4 Developer’s documentation: release procedure

The release procedure is automated through GitHub Actions. To create a new release:

- Update `docs/history.rst` with a summary of the new version’s changes.
- Bump version in `sncosmo/__init__.py`.
- Ensure that the tests have all completed successfully and that the docs are looking good.
- Create a new release through the releases tab on GitHub, and tag it with the latest version.
- Copy the change list into the release description.
- Publish the release.

#### Packaging and Docs

- GitHub Actions will trigger after each release and build compiled wheels and source distributions. These will then be pushed to PyPI.
- A conda build should start (with some delay) via a bot pull request at <https://github.com/conda-forge/sncosmo-feedstock>. Merge the PR once it passes all tests.
- The docs for the release will show up on [readthedocs.org](https://readthedocs.org) as the new `stable` version.
- Check out the source code: <https://github.com/sncosmo/sncosmo>
- Report bugs, request features: <https://github.com/sncosmo/sncosmo/issues>
- User & developer mailing list: <https://groups.google.com/forum/#!forum/sncosmo>



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- [S11] Sako et al. 2011
- [H07] Hsiao et al. 2007
- [G10] Guy et al. 2010
- [B14b] Betoule et al. 2014
- [H17] Hounsell et al. 2017
- [P13] Pereira et al. 2013
- [Whalen13] Whalen et al. 2013
- [Jha07] Jha, Riess and Kirshner 2007
- [Saunders18] Saunders et al. 2018
- [Leget20] Leget et al. 2020
- [1] extracted from SNANA’s SCDATA\_ROOT on 29 March 2013.
- [2] extracted from the SNooPy package on 21 Dec 2012.
- [3] extracted from SNANA’s SCDATA\_ROOT on 15 August 2013.
- [4] See Kenworthy et al. 2021, ApJ, submitted.
- [5] extracted from SNANA’s SCDATA\_ROOT on 24 April 2018. SALT2 model with wide wavelength range, Hounsell et al. 2017
- [6] extracted from SNANA’s SCDATA\_ROOT on 5 August 2014.
- [7] Templates from Vincenzi et al. 19. Each template is extended in the ultraviolet (1600Å) and in the near infrared (10000Å). Each template can be used in its original version (v19-sn-name) or in its host dust extinction corrected version (v19-sn-name-corr).
- [8] private communication (D.Whalen, May 2014).
- [9] In MLCS2k2 language, this version corresponds to “MLCS2k2 v0.07 rv19-early-smix vectors”
- [B90] Bessell 1990, Table 2
- [B14a] Betoule et al. (2014), Footnote 21

- [D10]      Doi et al. 2010, Table 4  
[T12]      Tonry 2012, Table 3

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