Bagpipes Documentation

Release 0.8.1

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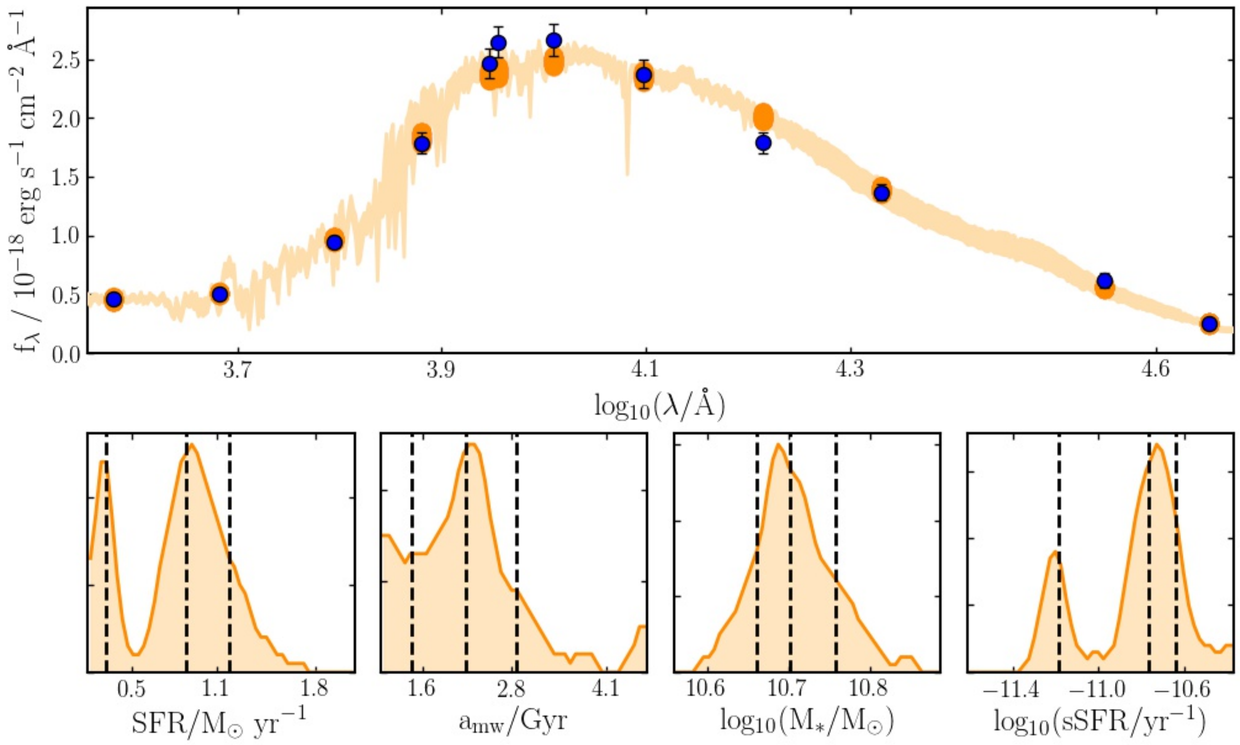
Contents

Bayesian Analysis of Galaxies for Physical Inference and Parameter EStimation is a state of the art Python code for modelling galaxy spectra and fitting spectroscopic and photometric observations.

Bagpipes is currently in a state of active development in the run-up to the release of version 1. Please email me if you have any queries, or find things which don't work as they're supposed to.



CHAPTER 1

Source and installation

Bagpipes is developed at GitHub, however the code cannot be installed from there, as the large model grid files aren't included in the repository. The code should instead be installed with pip:

```
pip install bagpipes
```

All of the code's Python dependencies will be automatically installed. The only non-Python dependency is the MultiNest nested sampling algorithm (used only for fitting). To install MultiNest see point 1 of the "on your own computer" section of the PyMultiNest installation instructions.

In my experience, the sequence of commands necessary to install MultiNest on a mac is as follows:

```
git clone https://github.com/JohannesBuchner/MultiNest
brew install gcc49
export DYLD_LIBRARY_PATH="/usr/local/bin/gcc-4.9:$DYLD_LIBRARY_PATH"
cd MultiNest/build
cmake ..
make
sudo make install
cd ../..
rm -r MultiNest
```

CHAPTER 2

Citation

Bagpipes is described in Section 3 of Carnall et al. 2018, if you make use of Bagpipes, please include a citation to this work in any publications. Please note development of the code has been ongoing since this work was published, so certain parts of the code are no longer as described.

CHAPTER 3

Getting started

The best place to get started is by looking at the iPython notebook examples. It's a good idea to tackle them in order as the later examples build on the earlier ones. These documentation pages contain a more complete reference guide.

Bagpipes is structured around three core classes:

- *model_galaxy*: for generating model galaxy spectra
- *galaxy*: for loading observational data into Bagpipes
- *fit*: for fitting models to observational data.

CHAPTER 4

Acknowledgements

A few of the excellent projects Bagpipes relies on are:

- The Bruzual & Charlot 2003 stellar population models.
- The Draine & Li 2007 dust emission models.
- The MultiNest nested sampling algorithm (Feroz et al. 2013)
- The PyMultiNest Python interface for Multinest (Buchner et al. 2014).
- The Cloudy photoionization code (Ferland et al. 2017).
- The Deepdish HDF5 loading/saving interface.

4.1 Making model spectra: model_galaxy

Model galaxy spectra and associated observables are created using the `model_galaxy` class. Check out the first iPython notebook example for a quick-start guide to making models.

class `bagpipes.`**`model_galaxy`**(*model_components*, *filt_list=None*, *spec_wavs=None*, *spec_units='ergscma'*, *phot_units='ergscma'*, *index_list=None*)

Builds model galaxy spectra and calculates predictions for spectroscopic and photometric observables.

Parameters

- **`model_components`** (*`dict`*) – A dictionary containing information about the model you wish to generate.
- **`filt_list`** (*`list - optional`*) – A list of paths to filter curve files, which should contain a column of wavelengths in angstroms followed by a column of transmitted fraction values. Only required if photometric output is desired.
- **`spec_wavs`** (*`array - optional`*) – An array of wavelengths at which spectral fluxes should be returned. Only required of spectroscopic output is desired.

- **spec_units** (*str - optional*) – The units the output spectrum will be returned in. Default is "ergscma" for ergs per second per centimetre squared per angstrom, can also be set to "mujy" for microjanskys.
- **phot_units** (*str - optional*) – The units the output spectrum will be returned in. Default is "ergscma" for ergs per second per centimetre squared per angstrom, can also be set to "mujy" for microjanskys.
- **index_list** (*list - optional*) – list of dicts containining definitions for spectral indices.

update (*model_components*)
Update the model outputs to reflect new parameter values in the model_components dictionary. Note that only the changing of numerical values is supported.

4.1.1 The model_components dictionary

The first and most important argument passed to `model_galaxy` is the `model_components` dictionary. This contains all of the physical information about the model you wish to create. A complete guide to the `model_components` dictionary is provided *here*.

4.1.2 Getting observables - photometry

In order to obtain predictions for photometric observations of a galaxy with the physical parameters defined in `model_components` it is necessary to define a list of filter curves through which observed fluxes should be calculated. This is done by defining a `filt_list`.

This is simply a list of paths (absolute or from the directory in which the code is being run) to the locations at which these filter curves are stored. The filter curve files should contain wavelengths in Angstroms in their first column and relative transmission values in their second.

Let's look at a simple example of some code which creates predictions for photometry through a series of filter curves. For this to work you'd first need to put the filter curve files in the correct location. For sourcing filter curves I recommed the SVO Filter Profile Service.

```
import bagpipes as pipes
import numpy as np

uvista_filt_list = ["uvista/CFHT_u.txt",
                    "uvista/CFHT_g.txt",
                    "uvista/CFHT_r.txt",
                    "uvista/CFHT_i+i2.txt",
                    "uvista/CFHT_z.txt",
                    "uvista/subaru_z",
                    "uvista/VISTA_Y.txt",
                    "uvista/VISTA_J.txt",
                    "uvista/VISTA_H.txt",
                    "uvista/VISTA_Ks.txt",
                    "uvista/IRAC1",
                    "uvista/IRAC2"]

model = pipes.model_galaxy(model_components, filt_list=uvista_filt_list)

model.plot()
```

We now have a Bagpipes model galaxy! The final command generates a plot of the predicted fluxes.

Photometry is accessible as `model.photometry`, which is a 1D array of flux values in erg/s/cm^2/A in the same order as the filter curves are specified in `filt_list`. The output flux units can be converted to microJanskys using the `model_galaxy` keyword argument `phot_units="mujy"`.

4.1.3 Getting observables - spectroscopy

The process for obtaining model spectroscopy is simpler, just pass an array containing the desired wavelength sampling in Angstroms as the `spec_wavs` keyword argument.

```
import bagpipes as pipes
import numpy as np

obs_wavs = np.arange(2500., 7500., 5.)

model = pipes.model_galaxy(model_components, spec_wavs=obs_wavs)

model.plot()
```

The output spectrum is stored as `model.spectrum` which is a two column array, containing wavelengths in Angstroms and spectral fluxes in erg/s/cm^2/A by default. The output flux units can be converted to microJanskys using the `model_galaxy` keyword argument `spec_units="mujy"`.

4.1.4 Getting observables - line fluxes

Emission line fluxes are stored in the `model_galaxy.line_fluxes` dictionary. The list of emission features is here. These are only non-zero if a `nebular` component is added to `model_components`.

Emission line naming conventions are the same as in Cloudy. The names in the above file are the keys for the lines in `model_galaxy.line_fluxes`. For example, the Lyman alpha flux is under:

```
model.line_fluxes["H  1  1215.67A"]
```

Emission line fluxes are returned in units of erg/s/cm^2.

4.1.5 Note on units at redshift zero

The units specified above apply at non-zero redshift, however at redshift zero the luminosity distance is zero which would lead to a division by zero error. At redshift zero the code instead returns luminosities, in erg/s/A for spectroscopy and photometry, and erg/s for emission lines.

4.1.6 Updating models

Creating a new `model_galaxy` is relatively slow, however changing parameter values in `model_components` and calling the `update` method of `model_galaxy` rapidly updates the output predictions described above.

It should be noted that the `update` method is designed to deal with changing numerical parameter values, not with adding or removing components of the model or changing non-numerical values such as the dust attenuation type.

4.2 The model_components dictionary

All of the physical parameters the user desires to specify for a `model_galaxy` object are passed in the `model_components` dictionary. This page will take you though all of the available options. For a quick introduction take a look at the first iPython notebook example.

Parameters are equal to mandatory if they must be specified, or equal to their default values if not.

4.2.1 Global parameters

There are a few global parameters which can be inserted directly into `model_components`.

```
model_components = {}
model_components["redshift"] = mandatory  # Observed redshift
model_components["t_bc"] = 0.01           # Max age of birth clouds: Gyr
model_components["veldisp"] = 0.          # Velocity dispersion: km/s

model_components["sfh_comp"] = sfh_comp   # Dict containing SFH info
```

All other parameter values must first be placed within component dictionaries which are then inserted into `model_components`. Aside from observed redshift, the only other requirement is that at least one star-formation history component must be added to `model_components` for it to be valid.

4.2.2 Star-formation history components

Each SFH component is an individual parametric model for the SFH of the galaxy. Bagpipes can build up complex star-formation histories by superimposing multiple components. Components of the same type should be labelled sequentially in `model_components` e.g. `burst1`, `burst2` etc.

All star-formation history components take the following keys:

```
sfh_comp = {}
sfh_comp["massformed"] = mandatory   # Log_10 total stellar mass formed: M_
↪Solar
sfh_comp["metallicity"] = mandatory  # Metallicity: Z_sol = 0.02
```

All SFH components also take one or more additional parameters describing their shape. All of the available options are listed below.

```
burst = {}                            # Delta function burst
burst["age"] = mandatory              # Time since burst: Gyr

constant = {}                         # tophat function
constant["age_max"] = mandatory       # Time since SF switched on: Gyr
constant["age_min"] = mandatory       # Time since SF switched off: Gyr

exponential = {}                      # Tau model e^-(t/tau)
exponential["age"] = mandatory        # Time since SFH began: Gyr
exponential["tau"] = mandatory        # Timescale of decrease: Gyr

delayed = {}                          # Delayed Tau model t*e^-(t/tau)
delayed["age"] = mandatory            # Time since SF began: Gyr
delayed["tau"] = mandatory            # Timescale of decrease: Gyr

```

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```
lognormal = {}                          # lognormal SFH
lognormal["tmax"] = mandatory           # Age of Universe at peak SF: Gyr
lognormal["fwhm"] = mandatory           # Full width at half maximum SF: Gyr

dblplaw = {}                            # double-power-law
dblplaw["alpha"] = mandatory            # Falling slope index
dblplaw["beta"] = mandatory             # Rising slope index
dblplaw["tau"] = mandatory              # Age of Universe at turnover: Gyr

custom = {}                             # A custom array of SFR values
custom["history"] = mandatory           # sfhist_array or "sfhist.txt": M_Solar/
↪yr
```

If a custom SFH component is specified, the "history" key must contain either an array containing or a string giving the path to a file containing the star formation history. In both cases the format is a column of ages in years followed by a column of star formation rates in Solar masses per year.

4.2.3 Nebular component

The inclusion of the nebular component tells Bagpipes to include emission lines and nebular continuum emission in the model. These come from pre-computed Cloudy grids. The nebular emission model has only one free parameter, log_10 of the ionization parameter. The metallicity of the gas in the stellar birth clouds is assumed to be the same as the stars producing the ionizing flux.

```
nebular = {}
nebular["logU"] = mandatory             # Log_10 of the ionization parameter.
```

4.2.4 Dust attenuation and emission component

The dust component governs attenuation and emission processes due to dust. Energy balance is assumed, such that all attenuated light is re-radiated.

Three dust attenuation models are implemented in Bagpipes, the Calzetti et al. (2000) model, the Cardelli et al. (1989) model, a model based on Charlot & Fall (2001) and the model of Salim et al. (2018). The dust emission models come from Draine + Li (2007).

```
dust = {}
dust["type"] = mandatory    # Attenuation law: "Calzetti", "Cardelli", "CF00"␣
↪or "Salim"
dust["Av"] = mandatory      # Absolute attenuation in the V band: magnitudes
dust["eta"] = 1.            # Multiplicative factor on Av for stars in birth␣
↪clouds

dust["n"] = 1.              # Power-law slope of attenuation law ("CF00" only)

dust["delta"] = 0.          # Deviation from Calzetti slope ("Salim" only)
dust["B"] = 0.              # 2175A bump strength ("Salim" only)

# Dust emission parameters
dust["qpah"] = 2.           # PAH mass fraction
dust["umin"] = 1.           # Lower limit of starlight intensity distribution
dust["gamma"] = 0.01        # Fraction of stars at umin
```

4.3 Loading observational data: galaxy

This section will introduce you to loading observational data. This is stored in the `galaxy` object. Check out the second iPython notebook example for a quick-start guide to loading data.

4.3.1 API documentation: galaxy

class `bagpipes.`**`galaxy`**(*ID*, *load_data*, *spec_units='ergscma'*, *phot_units='mujy'*, *spectrum_exists=True*, *photometry_exists=True*, *filt_list=None*, *out_units='ergscma'*, *load_indices=None*, *index_list=None*, *index_redshift=None*, *input_spec_cov_matrix=False*)

A container for observational data loaded into Bagpipes.

Parameters

- **`ID`** (*`str`*) – string denoting the ID of the object to be loaded. This will be passed to load_data.
- **`load_data`** (*`function`*) – User-defined function which should take ID as an argument and return spectroscopic and/or photometric data. Spectroscopy should come first and be an array containing a column of wavelengths in Angstroms, then a column of fluxes and finally a column of flux errors. Photometry should come second and be an array containing a column of fluxes and a column of flux errors.
- **`filt_list`** (*`list - optional`*) – A list of paths to filter curve files, which should contain a column of wavelengths in angstroms followed by a column of transmitted fraction values. Only needed for photometric data.
- **`spectrum_exists`** (*`bool - optional`*) – If you do not have a spectrum for this object, set this to False. In this case, load_data should only return photometry.
- **`photometry_exists`** (*`bool - optional`*) – If you do not have photometry for this object, set this to False. In this case, load_data should only return a spectrum.
- **`spec_units`** (*`str - optional`*) – Units of the input spectrum, defaults to ergs s^-1 cm^-2 A^-1, "ergscma". Other units (microjanskys; mujy) will be converted to ergscma by default within the class (see out_units).
- **`phot_units`** (*`str - optional`*) – Units of the input photometry, defaults to microjanskys, "mujy" The photometry will be converted to ergscma by default within the class (see out_units).
- **`out_units`** (*`str - optional`*) – Units to convert the inputs to within the class. Defaults to ergs s^-1 cm^-2 A^-1, "ergscma".
- **`index_list`** (*`list - optional`*) – list of dicts containining definitions for spectral indices.
- **`load_indices`** (*`function or str - optional`*) – Load spectral index information for the galaxy. This can either be a function which takes the galaxy ID and returns index values in the same order as they are defined in index_list, or the str "from_spectrum", in which case the code will measure the indices from the observed spectrum for the galaxy.
- **`index_redshift`** (*`float - optional`*) – Observed redshift for this galaxy. This is only ever used if the user requests the code to calculate spectral indices from the observed spectrum.

4.3.2 The load_data function

The most important argument passed to `galaxy` is the `load_data` function, which you will need to write to access your data files and return your data. `load_data` should take an ID string and return observed spectroscopic and/or photometric data in the correct format and units (see below).

For example:

```
import bagpipes as pipes

eg_filt_list = ["list", "of", "filters"]

def load_data(ID):
    # Do some stuff to load up data for the object with the correct ID number

    return spectrum, photometry


ID_number = "0001"

galaxy = pipes.galaxy(ID_number, load_data, filt_list=eg_filt_list)

galaxy.plot()
```

This will plot the data returned by the `load_data` function.

By default, Bagpipes expects spectroscopic and photometric data to be returned by `load_data` in that order. If you do not have both, you must pass a keyword argument to `galaxy`, either `spectrum_exists=False` or `photometry_exists=False`.

The format of the spectrum returned by `load_data` should be a 2D array with three columns: wavelengths in Angstroms, fluxes in erg/s/cm^2/A and flux errors in the same units (can be changed to microJansksys with the `spec_units` keyword argument). These will be stored in `galaxy.spectrum`.

The format of the photometry returned by `load_data` should be a 2D array with a column of fluxes in microJanskys and a column of flux errors in the same units (can be changed to erg/s/cm^2/A with the `phot_units` keyword argument). The fluxes should be in the same order as the filters in your `filt_list`. Bagpipes will calculate effective wavelengths for each filter and store these along with the input data in `galaxy.photometry`.

4.4 Fitting observational data: fit

This section describes fitting observational data using the `fit` class. Check out the third iPython notebook example for a quick-start guide and the fourth for some more advanced options.

4.4.1 API documentation: fit

class `bagpipes.`**`fit`**(*galaxy*, *fit_instructions*, *run='.'*, *time_calls=False*, *n_posterior=500*)

Top-level class for fitting models to observational data. Interfaces with MultiNest to sample from the posterior distribution of a fitted_model object. Performs loading and saving of results.

Parameters

- **galaxy** (`bagpipes.galaxy`) – A galaxy object containing the photomeric and/or spectroscopic data you wish to fit.

- **`fit_instructions`** (*`dict`*) – A dictionary containing instructions on the kind of model which should be fitted to the data.
- **`run`** (*`string - optional`*) – The subfolder into which outputs will be saved, useful e.g. for fitting more than one model configuration to the same data.
- **`time_calls`** (*`bool - optional`*) – Whether to print information on the average time taken for likelihood calls.
- **`n_posterior`** (*`int - optional`*) – How many equally weighted samples should be generated from the posterior once fitting is complete. Default is 500.

`fit`(*verbose=False*, *n_live=400*, *mpi_off=False*)

Fit the specified model to the input galaxy data.

Parameters

- **`verbose`** (*`bool - optional`*) – Set to True to get progress updates from the sampler.
- **`n_live`** (*`int - optional`*) – Number of live points: reducing speeds up the code but may lead to unreliable results.

4.4.2 The fit_instructions dictionary

The two arguments passed to the `fit` class are a `galaxy` object (described in the *loading observational data* section) and the `fit_instructions` dictionary, which contains instructions on the model to be fitted to the data.

This is very similar to the *model_components* dictionary, however some additional options are available so that as well as being fixed, parameters can be fitted and prior probability density functions specified. A complete guide to the `fit_instructions` dictionary is provided *here*.

4.4.3 Running the sampler

The MultiNest nested sampling algorithm can be run in order to sample from the posterior distribution using the `fit` method of the `fit` class. Nested sampling is similar to MCMC with a few key differences, for example no initial starting parameters are necessary.

4.4.4 Obtaining fitting results

The main output of the code is a set of samples from the posterior probability distribution for the model parameters. The code will also calculate samples for a series of derived quantites, e.g. the living stellar mass, ongoing star-formation rate etc. Samples are stored in the fit.posterior.samples dictionary. More information is available in the third iPython notebook example.

4.4.5 Saved outputs

The code saves basic output quantities needed to reconstruct the fit results without re-running the sampler as a hdf5 file under `pipes/posterior/<ID>.h5`. When the same fit is run again the results of the previous sampler run will be loaded by default, and you will not be able to re-fit the data. If you want to start over you'll need to delete the saved file or change the run (see below).

4.4.6 Making output plots

Bagpipes can provide several standard plots. These are saved under the `pipes/plots/` folder.

These can be generated with:

```
fit.plot_spectrum_posterior()  # Shows the input and fitted spectrum/
↪photometry
fit.plot_sfh_posterior()       # Shows the fitted star-formation history
fit.plot_1d_posterior()        # Shows 1d posterior probability distributions
fit.plot_corner()              # Shows 1d and 2d posterior probability␣
↪distributions
```

You may find some of the functions available under pipes.plotting helpful when generating your own custom plots

4.4.7 The run keyword argument

Often we will want to fit a series of different models to data, changing star-formation histories, parameter limits, priors etc. In order to quickly switch between different fitting runs without deleting output posteriors we can specify the `run` keyword argument of `fit`. This will cause all outputs in `pipes/posterior/` and `pipes/plots/` to be saved into a further subdirectory with the name passed as `run`, e.g. `pipes/posterior/<run>/`.

4.5 The fit_instructions dictionary

The `fit_instructions` dictionary is similar to the `model_components` dictionary described in the *making model galaxies* section. Available options are the same, however as well as fixed values, the user can specify parameters to be fitted by defining a prior range and probability density function.

For example, a very simple model could be fitted with the following `fit_instructions` dictionary:

```
burst = {}
burst["age"] = (0., 15.)                    # Vary age from 0 to 15 Gyr
burst["metallicity"] = (0., 2.5)            # Vary metallicity from 0 to 2.5␣
↪Solar
burst["massformed"] = (0., 13.)             # Vary log_10(mass formed) from 0␣
↪to 13

fit_instructions = {}
fit_instructions["burst"] = burst           # Add the burst sfh component to␣
↪the fit
fit_instructions["redshift"] = (0., 10.)    # Vary observed redshift from 0 to␣
↪10
```

Note that the code also automatically imposes a limit that no stars can form before the big bang, so the upper limit on the prior on burst["age"] will vary with observed redshift.

Combining this with the simple example from the *inputting observational data* section:

```
import bagpipes as pipes

eg_filt_list = ["list", "of", "filters"]

def load_data(ID, filtlist):
```

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```
    # Do some stuff to load up data for the object with the correct ID number

    return spectrum, photometry


ID_number = "0001"

galaxy = pipes.galaxy(ID_number, load_data, filt_list=eg_filt_list)

fit = pipes.fit(galaxy, fit_instructions)
```

There is no need to vary all of the parameters in `fit_instructions`. Parameters can still be fixed to single values just like in `model_components`. Additionally, parameters can be set to mirror other parameters which are fixed or fitted. For example:

```
burst1 = {}                                      # A burst component
burst1["age"] = 0.1                              # Fix age to 0.1 Gyr
burst1["metallicity"] = (0., 2.5)                # Vary metallicity from 0 to 2.
↪5 Solar
burst1["massformed"] = (0., 13.)                 # Vary log_10(mass formed)␣
↪from 0 to 13

burst2 = {}                                      # A second burst component
burst2["age"] = 1.0                              # Fix the age to 1.0 Gyr
burst2["metallicity"] = "burst1:metallicity"     # Mirror burst1:metallicity
burst2["massformed"] = (0., 13.)                 # Vary log_10(mass formed)␣
↪from 0 to 13

fit_instructions = {}
fit_instructions["burst1"] = burst1              # Add the burst1 sfh component␣
↪to the fit
fit_instructions["burst2"] = burst2              # Add the burst2 sfh component␣
↪to the fit
fit_instructions["redshift"] = (0., 10.)         # Vary observed redshift from␣
↪0 to 10
```

4.5.1 Adding priors

At the moment, all of the parameters in the above example are fitted with uniform priors by default. We can add further keys to the relevant dictionaries to specify different priors. For example, if we wanted the prior on stellar metallicity to be uniform in log_10 of the parameter:

```
burst = {}
burst["age"] = (0., 13.)
burst["metallicity"] = (0.01, 5.)
burst["metallicity_prior"] = "log_10"
burst["massformed"] = (0., 13.)
```

The list of currently available priors is:

```
component = {}
component["parameter_prior"] = "uniform"   # Uniform prior
component["parameter_prior"] = "log_10"    # Uniform in log_10(parameter)
component["parameter_prior"] = "log_e"     # Uniform in log_e(parameter)
```

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```
component["parameter_prior"] = "pow_10"    # Uniform in 10**parameter
component["parameter_prior"] = "recip"     # Uniform in 1/parameter
component["parameter_prior"] = "recipsq"   # Uniform in 1/parameter**2

component["parameter_prior"] = "Gaussian"  # Gaussian, also requires:
component["parameter_prior_mu"] = 0.5      # Gaussian mean
component["parameter_prior_sigma"] = 0.1   # Gaussian standard dev.
```

The limits specified are still applied when a Gaussian prior is used, for example:

```
fit_instructions["redshift"] = (0., 1.)
fit_instructions["redshift_prior"] = "Gaussian"
fit_instructions["redshift_prior_mu"] = 0.7
fit_instructions["redshift_prior_sigma"] = 0.2
```

will result in a Gaussian prior on redshift centred on 0.7 with standard deviation 0.2 but which is always constrained to be between 0 and 1.

4.6 Fitting multiple objects: fit_catalogue

This section describes fitting a catalogue of objects with the same model using the `fit_catalogue` class. Check out the sixth iPython notebook example for a quick-start guide.

4.6.1 API documentation: fit_catalogue

class bagpipes.**fit_catalogue**(*IDs*, *fit_instructions*, *load_data*, *spectrum_exists=True*, *photometry_exists=True*, *make_plots=False*, *cat_filt_list=None*, *vary_filt_list=False*, *redshifts=None*, *redshift_sigma=0.0*, *run='.'*, *analysis_function=None*, *time_calls=False*, *n_posterior=500*, *full_catalogue=False*)

Fit a model to a catalogue of galaxies.

Parameters

- **IDs** (*list*) – A list of ID numbers for galaxies in the catalogue
- **fit_instructions** (*dict*) – A dictionary containing the details of the model to be fitted to the data.
- **load_data** (*function*) – Function which takes ID as an argument and returns the model spectrum and photometry. Spectrum should come first and be an array with a column of wavelengths in Angstroms, a column of fluxes in erg/s/cm^2/A and a column of flux errors in the same units. Photometry should come second and be an array with a column of fluxes in microjanskys and a column of flux errors in the same units.
- **spectrum_exists** (*bool - optional*) – If the objects do not have spectroscopic data set this to False. In this case, load_data should only return photometry.
- **photometry_exists** (*bool - optional*) – If the objects do not have photometric data set this to False. In this case, load_data should only return a spectrum.
- **run** (*string - optional*) – The subfolder into which outputs will be saved, useful e.g. for fitting more than one model configuration to the same data.

- **make_plots** (*bool – optional*) – Whether to make output plots for each object.
- **cat_filt_list** (*list – optional*) – The filt_list, or list of filt_lists for the catalogue.
- **vary_filt_list** (*bool – optional*) – If True, changes the filter list for each object. When True, each entry in cat_filt_list is expected to be a different filt_list corresponding to each object in the catalogue.
- **redshifts** (*list – optional*) – List of values for the redshift for each object to be fixed to.
- **redshift_sigma** (*float – optional*) – If this is set, the redshift for each object will be assigned a Gaussian prior centred on the value in redshifts with this standard deviation. Hard limits will be placed at 3 sigma.
- **analysis_function** (*function – optional*) – Specify some function to be run on each completed fit, must take the fit object as its only argument.
- **time_calls** (*bool – optional*) – Whether to print information on the average time taken for likelihood calls.
- **n_posterior** (*int – optional*) – How many equally weighted samples should be generated from the posterior once fitting is complete for each object. Default 500.
- **full_catalogue** (*bool – optional*) – Adds minimum chi-squared values and rest-frame UVJ mags to the output catalogue, takes extra time, default False.

fit (*verbose=False*, *n_live=400*, *mpi_serial=False*)

Run through the catalogue fitting each object.

Parameters

- **verbose** (*bool – optional*) – Set to True to get progress updates from the sampler.
- **n_live** (*int – optional*) – Number of live points: reducing speeds up the code but may lead to unreliable results.
- **mpi_serial** (*bool – optional*) – When running through mpirun/mpiexec, the default behaviour is to fit one object at a time, using all available cores. When mpi_serial=True, each core will fit different objects.

fit_mpi_serial (*verbose=False*, *n_live=400*)

Run through the catalogue fitting multiple objects at once on different cores.

4.6.2 Saving of output catalogues

`fit_catalogue` will generate an output catalogue of posterior percentiles for all fit parameters plus some basic derived parameters. This is saved in the `pipes/cats` folder as `<run>.fits`.

4.6.3 Parallelisation

Bagpipes now supports parallelisation with MPI using the python package mpi4py. You can run both fit or fit_catalogue with MPI, just do `mpirun/mpiexec -n nproc python fit_with_bagpipes.py`. The default behaviour is to fit one object at a time using all available cores, this is useful for complicated models (e.g. fitting spectroscopy).

For catalogue fitting an alternative approach is also available, in which multiple objects are fitted at once, each using one core. This option can be activated using the `mpi_serial` keyword argument of fit_catalogue. This is better for fitting relatively simple models to large catalogues of photometry. This option currently requires a slightly modified version of pymultinest, which can be downloaded from this github repository. Please get in touch if you're having difficulty getting this to work.

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