Powderday Documentation

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Contents

powderday is a dust radiative transfer package designed to interface with galaxy formation simulations in order to produce realistic spectral energy distributions and images. The code utilizes‘fsps <https://code.google.com/p/fsps/source/checkout>‘_ (and its python hooks, python-fsps) for stellar SEDs, and Hyperion for dust radiative transfer. Threaded throughout is yt.

The code has two principle aims - to be flexible (and extremely modular), and to be easy to use. The package is written in python, though makes use of fortran, C and cython.

As of now, the code works principally for Gadget, Gizmo and other variants. Support for Gasoline, RAMSES, ART and Enzo are planned however. The current timeline is for TIPSY front ends to be built over Spring 2015, with AMR support to follow

Finally, this code benefits from the contributions, either directly to this software, or indirectly by contributions to dependency software, by many astrophysicists, including Matt Turk, Tom Robitaille, Robert Thompson, Charlie Conroy, Dan Forman-Mackey and Phil Hopkins.

Important: Disclaimer:

While the developers have made every effort to ensure that the code is bug-free, bugs invariably find their way in. The developers are not responsible for incorrect results, arising either from inherent bugs in the code, or mistakes in usage. Any questions regarding the code or usage should be sent to the mailing list.

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CHAPTER 1

Getting Started

1.1 Overview of Requirements

- **python2.x**
  - numpy (any version except 1.10.*)
  - scipy
  - astropy
  - Atpy
  - h5py
  - ipdb
- **compilers**
  - gcc
  - gfortran
- **Additional Packages (with Instructions Below)**
  - mercurial <http://mercurial.selenic.com/>
  - git <http://git-scm.com/>
  - powderday <http://bitbucket.org/desika/powderday>
  - yt <http://yt-project.org>
  - FSPS <https://code.google.com/p/fsps/source/checkout>
  - python-fsps <http://dan.iel.fm/python-fsps/current/>
  - Hyperion <http://www.hyperion-rt.org/>
  - Hyperion Dust Files <http://docs.hyperion-rt.org/en/stable/dust/dust.html>

1.2 Installation

1.2.1 All in One Installer

The first stop is to try the all-in-one installer for powderday. This is available at the main download page <https://bitbucket.org/desika/powderday/downloads> from the Bitbucket repository. This is a bash script that will append relevant path names to your .bashrc, as well as attempt to go package-by-package and install everything. The plus side is that if it works, it's super easy. The downside is that if a package installation fails, you might not catch it because the bash script will go on to the next package. This installer assume gnu C and Fortran compilers.

Something that has worked for a number of users is to download the all-in-one installer, and then copy and paste the instructions for each package one at a time. This can alert the user to package failures.

1.2.2 Manual Installation

What follows is a self-contained installation manual, though for problematic installs of any of the sub packages, it's definitely best to visit the main docs on the main software site (which are always linked below in each subsection).

1.2.3 python

powderday currently only works with python 2.x. The code was developed on, and principally tested with python 2.7.

1.2.4 mercurial

You'll need this to clone powderday using mercurial (hg). If you don't want to install mercurial, then first install yt (before powderday) - yt ships with its own hg which you can optionally use.

1.2.5 powderday

Simply clone the latest and greatest from the repo:

```
>hg clone https://desika@bitbucket.org/desika/powderday
```

And that's it! Once it's cloned, there's no subsidiary installation commands.

1.2.6 yt

powderday has yt threaded throughout, and thus needs the software to be installed to function. If you already have yt installed, be sure that it's yt 3.x (i.e at least the 'stable' branch).

If you don't have yt already installed, it's super easy! There are many ways to do this (as directed on the yt project website. We require the standalone installer script for the Development version. This will ensure that bugs caught in or bleeding-edge features of yt are included.

1.2.7 fsps

fsps can be checked out with:

```
> git clone https://github.com/cconroy20/fsps
```

and directions to the installation are in the Manual

It's likely going to be necessary downstream when installing python-fsps to have the -fPIC flags set in fsps when making. So, in the Makefile of fsps , set:

```
>F90FLAGS = -O -cpp -fPIC
```

Additionally, at this time powderday doesn't work with the default MIST Isochrones. To fix this, you'll need to edit sps_vars.f90 in fsps to look like:

```
!------set the isochrone library------!
#define MIST 0
!Padova models circa 2008
#define PADOVA 1
#define PARSEC 0
#define BASTI 0
#define GENEVA 0
```

Finally, the SPS_HOME variable must be set in your environment to point to the FSPS/src directory. For example, if your environment is bash, in your .bashrc set something along the lines of:

```
>export SPS_HOME=/Users/desika/fsps/
```

1.2.8 python-fsps

powderday depends on python hooks for fsps written by Daniel Foreman-Mackey and others called python-fsps. There are a few ways to install it. Perhaps the easiest is via a pip installer:

```
>pip install fsps
```

Though you could also install the development version:

```
>git clone https://github.com/dfm/python-fsps.git
>cd python-fsps
>python setup.py install
```

You can test the installation by opening python and typing:

```
>import fsps
```

1.2.9 Hyperion

Hyperion is the main work horse of powderday. The full directions for installation are well-described on the main Hyperion website. Here, we summarize the installation which should get most users through without any real difficulty.

1. First download the tarball and unpack it.:

   ```
   >tar -xzvf hyperion.xxx
   >cd hyperion.xxx
   ```

2. Install the fortran dependencies:

```
>cd deps/fortran
>python install.py <prefix>
```

where <prefix> is where you want the libraries to be installed. To avoid conflicts with other packages, I usually install somewhere like:

```
>python install.py /usr/local/hyperion
```

as suggested by the Hyperion docs. Ensure that the following commands return something sensible:

```
>which mpif90
>which h5fc
```

if not, your path probably needs to include wherever the <prefix> directory pointed to.

3. Install any remaining python dependencies. These are listed here
4. Install Hyperion itself. To do this:

```
>cd hyperion.xxx
>python setup.py install
```

or:

```
>python setup.py install --user
```

if you don't have root access. At this point:

```
>import hyperion
```

from within python should work, and typing:

```
>hyperion
```

at the command line should return something along the lines of:

```
>usage: hyperion [-h] [-f] [-m n_cores] input output
>hyperion: error: too few arguments
```

if not, check the the path that is near one of the last lines of the setup.py installation (that is something associated with the number 755) and make sure it's in your path. Ir's most likely to be a python binaries directory.

You then have to install the Fortran Binaries:

```
>./configure  --prefix=prefix
>make
>make install
```

where the prefix is wherever you installed the Fortran libraries before. Make sure this works by typing at the command line:

```
>hyperion_sph
```

which should return something like:

```
>Usage: hyperion_sph [-f] input_file output_file


.. _Hyperion_dust:
```

1.2.10 Hyperion Dust Files

Unless you've written your own dust files, you will likely want to use the pre-compiled dust files developed by Tom Robitaille (though don't ship with Hyperion due to their size). To install these download them here: http://docs.hyperion-rt.org/en/stable/dust/dust.html. Then to install:

```
>tar xvzf hyperion-dust-xxx.tar.gz
>cd hyperion-dust-0.1.0
>python setup.py build_dust
```

If you want to use the PAH model in powderday, you'll additionally need these files in the same dust directory. To download, click on the link, then click 'raw' on the right side of each page.

1. https://github.com/hyperion-rt/paper-galaxy-rt-model/blob/master/dust/big.hdf5
2. https://github.com/hyperion-rt/paper-galaxy-rt-model/blob/master/dust/vsg.hdf5
3. https://github.com/hyperion-rt/paper-galaxy-rt-model/blob/master/dust/usg.hdf5

Please note the caveat that the PAH files are generated using some approxmations described in Robitaille et al., and we encourage the user of these PAH files to read this paper, especially section 3.4.2.

1.3 Troubleshooting your Installation

1.3.1 python-fsps installation issues

1. python-fsps can't find f2py

   f2py is a numpy package that is sometimes named f2py2.7 by numpy. At the same time, python-fsps expects it to be called f2py (as it sometimes is; for example in Anaconda). So, you might need to locate f2py (it ships with yt, so if you for example use the yt python) you need to link the following files:

   ```
   >cd /Users/desika/yt-x86_64/bin
   >ln -s f2py2.7 f2py
   ```

   and:

   ```
   >cd /Users/desika/yt-x86_64/lib/python2.7/site-packages
   >ln -s numpy/f2py/ f2py
   ```

   This should hopefully fix it.

2. Issues with 'f2py' in the python-fsps installation:

   Numpy has made some changes to f2py in the 1.10.x version of numpy. The easiest fix is to use a non 1.10.* version of numpy (thanks to Ben Johnson for finding this).

3. python-fsps has mysterious installation failures. Often this has to do with a bad FSPS compilation. Even if it seems like FSPS has compiled, it may not actually execute properly if the correct compilers aren't set in the MakeFile. Thanks to Ena Choi for pointing this one out.

CHAPTER 2

Quickstart

In the examples subdirectory of the powderday root directory are some example snapshots for different hydro codes suppported thusfar. This will likely change over time as the code evolves and parameter files change. Also, eventually the examples will migrate to the agora project snapshots.

For each example file there should be two parameter files that will be reasonable for the associated snapshot, though you'll need to edit the hard linked directories that specify where (e.g.) dust files are and output should go. To run, type (in the powderday) source directory:

```
>python pd_front_end.py <example directory> <parameters_master_file>
<parameters_model_file>
```

Note - the .py extensions on the parameter files need to be left off.

2.1 Gadget/Gizmo

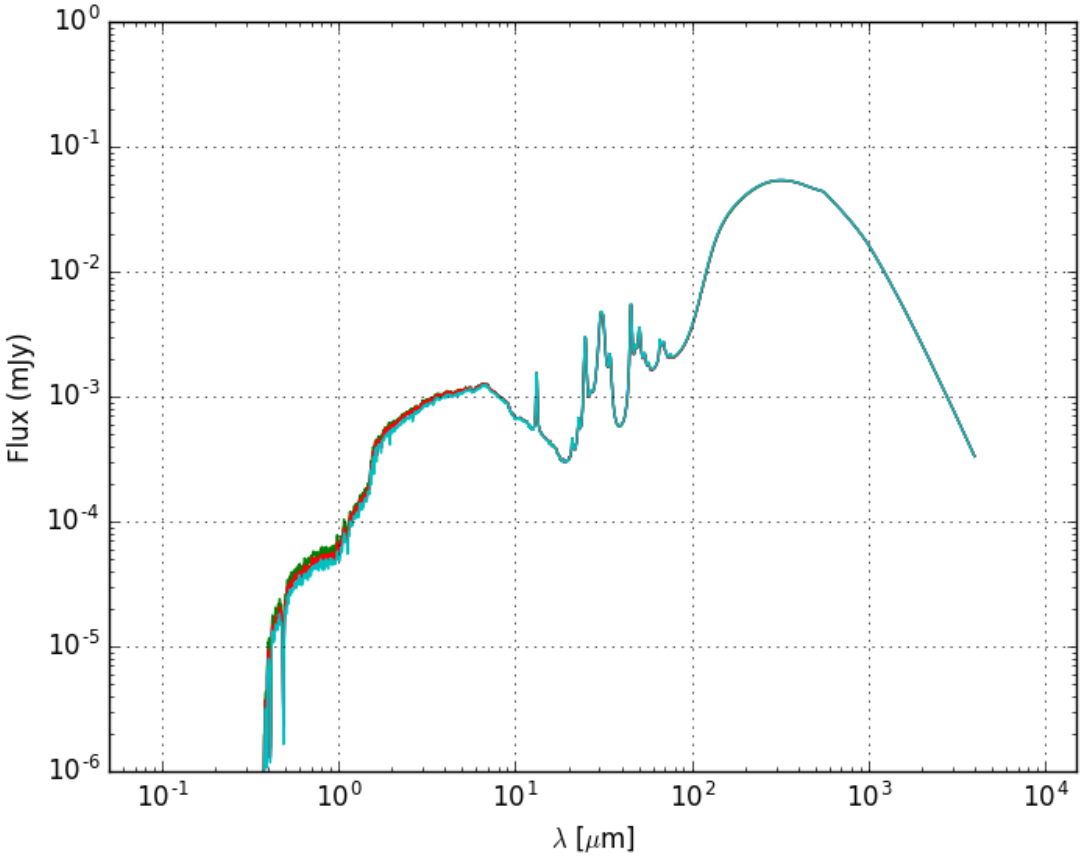
The example simulation is a cosmological zoom simulation of a Milky Way mass galaxy that can be downloaded here (6 GB download):

<https://www.dropbox.com/s/g6d47z3pm8l18p7/snapshot_134.hdf5?dl=0>

To run the code, you would type:

```
>python pd_front_end.py examples/gadget/mw_zoom parameters_master_401 parameters_
↪model_401
```

The SED (placed at z = 3 with a Planck13 cosmology) looks like:



and an example plotting code can be found in the convenience subdirectory of the powderday root directory.

2.2 Gasoline/Changa

CHAPTER 3

Detailed Description of Parameters

There are two parameters files - parameters_master and parameters_model. The distinction between where a parameter goes is somewhat arbitrary, but is based on the following. Parameters_master tends to contain parmaeters that will likely be shared amongst all snapshots in a given galaxy run, while parameters_model are parameters that might change from run to run (like the snapshot name or the galaxy center).

The parameters files are (somewhat non-traditionally) written as python code files because this enables you to embed little snippets in them that may be particular to your galaxy run. For example, for gadget snapshot naming conventions, it can be useful to have a snippet along the lines of:

```
Gadget_snap_num = 20
if Gadget_snap_num < 10:
   snapnum_str = '00'+str(Gadget_snap_num)
elif Gadget_snap_num >= 10 and Gadget_snap_num <100:
   snapnum_str = '0'+str(Gadget_snap_num)
else:
   snapnum_str = str(Gadget_snap_num)

Gadget_snap_name = 'snapshot_'+snapnum_str+'.hdf5'
```

That puts the correct number of 0's in front of the snapshot name.

3.1 parameters_master

3.1.1 Resolution Keywords

oref Over Refinement of the Octree - 1 means each data holding cell (a False) gets split into 8 one more time. Very heavy on the memory. Default is 0.

n_ref Threshold number of particles to refine over. When nparticles > n_ref the octree refines further. Default is 64.

zoom_box_len Side length to zoom in on. Is +/- zoom_box_len from the center. Units are proper kpc. So, a grid centered on [0,0,0] with zoom_box_len = 200 would extend from [-200,200] kpc in physical units at the redshift of the simulation.

bbox_lim Initial bounding box of grid for SPH simulations (+/- bbox_lim). Units are kpc. This must encompass all of the particles in a simulation currently. This just has to be a big number, but you want to be careful of making *too* large as precision limitations only allow for up to 20 levels of refinement.

3.1.2 Parallelization

n_processes Number of MPI processes to run the radiative transfer on. Note, the stellar population synthesis will only run on as many processors as are on a core since its parallelization is pool.map (not MPI)

3.1.3 RT Information

For all photon counts, a decent rule of thumb is 10-100x the number of grid cells that you have, though of course you should check the convergence properties of your simulation.

n_photons_initial Number of photons to use in main iterations (for the whole grid) for specific energy and temperature calculations.

n_photons_imaging Number of photons to use for the SED/image calculation

n_photons_raytracing_sources If raytracing is set (which is the default hard-coded into the code), number of raytracing photons to use for source emission.

n_photons_raytracing_dust Similar to n_photons_raytracing_sources but for dust emission.

3.1.4 Dust Information

dustdir String. Path to where your dust files are. String format - (e.g. '/home/desika/hyperion-dust-0.1.0/dust_files/')

dustfile String. Name of your main dust file. String format - (e.g. 'd03_3.1_6.0_A.hdf5')

PAH Boolean - True means use model for PAHs, False means don't.

dusttometals_ratio Dust mass to metals mass ratio

enforce_energy_range Boolean. False ensures energy conservation. But the emisivities may not be strictly correct if the energy in a cell is out of range of the emissivities. True modifies the energy in the simulation, but ensures that the emissivities are consistent with the energy. See: <http://docs.hyperion-rt.org/en/latest/api/hyperion.model.Model.html?highlight=enforce#hyperion.model.Model.set_enforce_energy_range>

3.1.5 Hydro Code Units

Currently these are actually not used in powderday). They remain in the parameters file as a placeholder though as we may need them as an over-ride if we find some HDF5 files don't contain this information.

unit_mass Mass code units for galaxy simulation. Units: Msun/h

unit_length Length code unit for galaxy simulation. Units: kpc/h

unit_age Stellar age units. Units: Gyr/h

unit_velocity Velocity code unit for galaxy simulation. Units: cm/s

3.1.6 Stellar SEDs Info

Force_Binning Boolean. True means force binning of the stellar SEDs (in bins of age and metallicity). False means don't. False results in an exact solution since the stellar SEDs are individually represented (as opposed to broken up into bins). This said, this can be very slow to run, and extremely hard on the memory.

COSMOFLAG Boolean. True means this is a cosmological simulation, False means idealized galaxy simulation.

imf_type IMF parameter for stellar pops calculations.

0. Salpeter
1. Chabrier
2. Kroupa
3. Van Dokkum
4. Dave

Though note options 3 and 4 are currently not supported.

pagb Weight given to post AGB stars. 1 is the default.

CF_on Boolean. If set to True, then enables the Charlot & Fall birthcloud models for all stars with age younger than birth_cloud_clearing_age.

birth_cloud_clearing_age Stars with age < birth_cloud_clearing_age have Charlot & Fall birthclouds (if CF_on == True). Meaningless if CF_on == False. Units: Gyr.

Z_init Forced metallicity increase in the newstar particles. Useful for idealized galaxy simulations where the stars can form out of pristine gas. Units are absolute (so 0.02 = Solar). Setting to 0 (default) means that you use the stellar metallicities as they come in the simulation (i.e. for Cosmological simulations).

disk_stars_age Age in Gyr of disk stars for idealized simulations. Meaningless for cosmological simulations. Note, if this is <=7, then these will live in Charlot & Fall birthclouds (if CF_on = True).

Note, for Gadget simulations, stars are divided into newstars, disk stars and bulge stars. For Tipsy outputs, the stars initalized with the simulation are auto-detected by their nonsensical ages, and assigned as disk stars. So, if there are stars initalized with your Tipsy simulation, assign their ages (and metallicities below) as disk stars.

bulge_stars_age As disk_stars_age but for bulge stars.

disk_stars_metals Metallicity of disk stars in FSPS metallicity units. See last page of FSPS manual for numbers. (e.g. 20 = Solar for Padova + BaSeL tracks). Meaningless for cosmological simulations.

bulge_stars_metals As disk_stars_metals but for bulge stars.

N_STELLAR_AGE_BINS Number of bins to bin the stellar ages in (boundaries are the oldest and youngest star particles; linear bins in log(age)).

N_MASS_BINS Meaningless parameter; place holder for future code additions.

metallicity_legend String. Location of the metallicity maps in FSPS for the stellar libraries you use. Currently Padova2007 is the default (hard coded into powderday), so this should point to something like: "/Users/desika/fsps/ISOCHRONES/Padova/Padova2007/zlegend_basel.dat"

3.1.7 Images and SED Parameters

NTHETA Number of polar angles to view galaxy at

3.1.8 GRID INFORMATION

MANUAL_CENTERING Boolean. False means the simulation automatically centers on the cell with the highest gas density peak. True means you center on x_cent,y_cent,z_cent as given in parameters_model.

3.1.9 DEBUGGING

You should probably never touch any of these.

3.2 parameters_model

Gadget_snap_name String - currently the snapshot name of your galaxy run. (Naming will change as other front ends built).

hydro_dir Location of snapshots

PD_output_dir String - location of where powderday output files should go.

Auto_TF_file String - name of the TF logical file to be written (doesn't need a path - will go into PD_output_dir)

Auto_dustdens_file String - name of the dust density ascii file to be written (doesn't need a path - will go into PD_output_dir)

inputfile String - name of the input HDF5 (rtin) file for powderday to write before radiative transfer begins.

outputfile String - name of the output HDF5 (rtout) file after radiative transfer

x_cent Location in grid coordinates of the x-coordinate of the center of your galaxy. Only pertinenet if MANUAL_CENTERING==True. Otherwise ignored by powderday.

y_cent As x_cent but for the y-coordinate

z_cent As x_cent but for the z-coordinate.

CHAPTER 4

Detailed Algorithm Description

CHAPTER 5

Convenience Scripts

The convenience scripts tend to live (where else) in the convenience subdirectory of the powderday root directory. There's a brief description of them here.

sed_plot Enter a redshift and rtout file name (in the editable header) and it will plot out an SED for all viewing angles in Jy. You'll want to manually monkey with the range, etc. This is mostly just serves as an example.

CHAPTER 6

Referencing

If you use powderday, we would definitely appreciate a hat tip toward the following papers that describe software that we depend on. We suggest either the following paragraph, or some variant.

This paper makes use of the powderday radiative transfer software, which is built on yt (Turk et al. 2011), Hyperion (Robitaille 2011), and FSPS (Conroy & Gunn, 2010).

References:

1. yt: Turk et al. 2011
2. Hyperion : Robitaille, 2011
3. fsps: Conroy & Gunn, 2010

CHAPTER 7

Troubleshooting and Known Issues

7.1 1. yt compilation complains with something like: "Error compiling Cython file"

Answer - try running:

```
pip install -U Cython
```

7.2 2. Python-fsps compilation returns errors along the lines of

Error:

```
compiling Fortran sources
Fortran f77 compiler: /usr/bin/gfortran -Wall -ffixed-form -fno-second-underscore -
↪fPIC -O3 -funroll-loops
Fortran f90 compiler: /usr/bin/gfortran -fPIC -fPIC -O3 -funroll-loops
```

Try re-compiling with the flag:

```
-fPIC
```

7.3 3. When running pd via a SLURM scheduler, you get the error when importing fsps

Error:

```
build/bdist.linux-x86_64/egg/fsps/__init__.py in <module>()
ImportError: Your FSPS version does not seem to be under git version control. FSPS is␣
↪available on github at https://github.com/cconroy20/fsps and should be cloned from␣
↪there
```

Comment out the lines in python-fsps/fsps/__init__.py surrounding the checking of githashes. (h/t to Ena Choi for uncovering this one).

7.4 4. If in powderday you start getting memory errors on the Pool process call that look like this:

Error:

```
calculating the SEDs for  42  bins
Traceback (most recent call last):
File "/ufrc/narayanan/desika.narayanan/pd/pd_front_end.py", line 139, in <module>
  m=add_binned_seds(df_nu,stars_list,diskstars_list,bulgestars_list,m)
File "/ufrc/narayanan/desika.narayanan/pd/source_creation.py", line 244, in add_
↪binned_seds
  #of star particles that go in every [wz,wa,wm]
File "/ufrc/narayanan/desika.narayanan/pd/SED_gen.py", line 225, in allstars_sed_gen
  p = Pool(processes = cfg.par.n_processes)
File "/ufrc/narayanan/desika.narayanan/miniconda2/lib/python2.7/multiprocessing/__
↪init__.py", line 232, in Pool
  return Pool(processes, initializer, initargs, maxtasksperchild)
File "/ufrc/narayanan/desika.narayanan/miniconda2/lib/python2.7/multiprocessing/pool.
↪py", line 159, in __init__
  self._repopulate_pool()
File "/ufrc/narayanan/desika.narayanan/miniconda2/lib/python2.7/multiprocessing/pool.
↪py", line 223, in _repopulate_pool
  w.start()
File "/ufrc/narayanan/desika.narayanan/miniconda2/lib/python2.7/multiprocessing/
↪process.py", line 130, in start
  self._popen = Popen(self)
File "/ufrc/narayanan/desika.narayanan/miniconda2/lib/python2.7/multiprocessing/
↪forking.py", line 121, in __init__
  self.pid = os.fork()
OSError: [Errno 12] Cannot allocate memory
```

Try reducing the number of n_processes in the parameters_master.py file

7.5 5. Assertion Error in SED generation related to zmet being out of range

Error:

```
assigning stars to SED bins
Running SPS for Binned SEDs
calculating the SEDs for  105  bins
Traceback (most recent call last):
File "pd_front_end.py", line 134, in <module>
m=add_binned_seds(df_nu,stars_list,diskstars_list,bulgestars_list,m)
File "source_creation.py", line 300, in add_binned_seds
binned_stellar_nu,binned_stellar_fnu_has_stellar_mass,disk_fnu,bulge_fnu = sg.
↪allstars_sed_gen(sed_bins_list_has_stellar_mass,diskstars_list,bulgestars_list)
File "SED_gen.py", line 216, in allstars_sed_gen
```

```
  add_neb_emission = cfg.par.add_neb_emission, add_agb_dust_model=cfg.par.add_agb_
↪dust_model)
File "build/bdist.linux-x86_64/egg/fsps/fsps.py", line 468, in __init__
  self.params[k] = kwargs.pop(k, v)
File "build/bdist.linux-x86_64/egg/fsps/fsps.py", line 1093, in __setitem__
  self.check_params()
File "build/bdist.linux-x86_64/egg/fsps/fsps.py", line 1067, in check_params
  "zmet={0} out of range [1, {1}]".format(self._params["zmet"], NZ)
  AssertionError: zmet=20 out of range [1, 12]
```

Recompile fsps with the libraries set to Padova (and not MIST) in sps_vars.f90. Also recompile python-fsps

CHAPTER 8

Getting Help

powderday has an email list serve on google groups. We encourage you to visit the group at http://groups.google.com/group/powderday and post any questions you have. You can also search the email archives there.

You can also directly email the group at [codename] AT googlegroups.com. For the benefit of future archive readers, if you could please include a descriptive subject line of the issue you're having, that would very helpful.

If a run crashes, it can oftentimes be very useful to post your parameters files as well as include which hash you're working off of. You can recover the hash by typing:

```
>hg id
```

And similarly, if you want a neat way to create a link out of your parameters files, you can type:

```
>yt pastebin parameters_master.py
>yt pastebin parmaeters_model.py
```

and two separate links will be created with the parameters files.

CHAPTER 9

Indices and tables

- genindex
- modindex
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