spiderman Documentation

Release 0.2.2

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CHAPTER 1

Installation

1.1 pip

The fastest way to get the latest stable version of `spiderman` up and running is through pip:

```
$ pip install spiderman-package
```

1.2 From source

To get the most up to date version of spider install directly from source, though stability is not guarenteed. The development version can be found on GitHub.

Installing from GitHub is straightforward, simply type

```
$ git clone https://github.com/tomlouden/SPIDERMAN
```

To 'clone' the repository, then `cd` into the folder and install using the setup script:

```
$ cd SPIDERMAN
$ sudo python setup.py install
```

And that's it! (Note that you'll need to `cd` out of the source directory **before** you can import `spiderman`.)

1.3 Tests

An Ipython notebook is included with a few examples, I recommend running it to test everything is working correctly. (built in test functions coming soon)

CHAPTER 2

Quickstart

Making a lightcurve — This is likely the basic task that you need SPIDERMAN to perform, to, for example, form the basis for a likelihood function being fed into an mcmc. Here is how to return a simulated lightcurve from SPIDERMAN, the fast way.

First, import spiderman into the namespace:

```
import spiderman as sp
```

Now, it is necesarry to generate a parameter object, this will be the main way of interacting with the code. Before doing so, you must specify which brightness model (link to brightness model page) you wish to use. In this example we will use the analytical formula from Zhang & Showman 2016, but many other options are availible (If you have a brightness model that is not represented, please contact me, and I will include it in the next release of the package).

```
spider_params = sp.ModelParams(brightness_model="zhang")
```

Now that the parameter object has been created, we can define the parameters as so:

```
spider_params.n_layers= 5
```

This parameter refers to the number of layers in the 2d "web" used to define the integration grid. 5 is typically acceptable for most availible data qualities. Next we will define the system parameters, using values suitable for WASP-43b

```
spider_params.t0= 200               # Central time of PRIMARY transit [days]
spider_params.per= 0.81347753       # Period [days]
spider_params.a_abs= 0.01526        # The absolute value of the semi-major axis [AU]
spider_params.inc= 82.33            # Inclination [degrees]
spider_params.ecc= 0.0              # Eccentricity
spider_params.w= 90                 # Argument of periastron
spider_params.rp= 0.1594            # Planet to star radius ratio
spider_params.a= 4.855              # Semi-major axis scaled by stellar radius
spider_params.p_u1= 0               # Planetary limb darkening parameter
spider_params.p_u2= 0               # Planetary limb darkening parameter
```

Note: these definitions are compatible with Batman (Kreidberg et al 2015)

Now set the parameters specific to the brightness model that we defined earlier:

```
spider_params.xi= 0.3         # Ratio of radiative to advective timescale
spider_params.T_n= 1128       # Temperature of nightside
spider_params.delta_T= 942    # Day-night temperature contrast
spider_params.T_s = 4500      # Temperature of the star
```

Since this uses model spectra, it is necessary to specify the bandpass with these parameters:

```
spider_params.l1 = 1.1e-6       # The starting wavelength in meters
spider_params.l2 = 1.7e-6       # The ending wavelength in meters
```

Warning: SPIDERMAN calculates ratios in flux density assuming a response function that is uniform in *energy flux*. If you want a response uniform in photon counts you must define a instrument response function (see Instrument Response section).

Now, define the times you wish the model to be evaluated at, let's do a single full orbit:

```
t= spider_params.t0 + np.linspace(0, + spider_params.per,100)
```

Finally, a lightcurve can be generated simply by using the "lightcurve" method:

```
lc = spider_params.lightcurve(t)
plt.plot(t,lc)
```

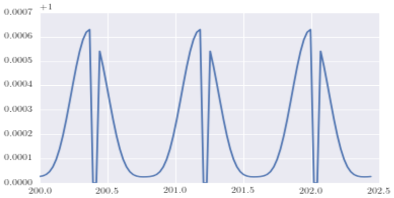


Fig. 1: The resulting lightcurve

Warning: SPIDERMAN currently only produces secondary eclipses and phase-curves - the primary eclipse will not be modelled! To model the primary eclipse an additional code, such as BATMAN (Kreidberg et al 2015) will be required.

It's that simple!

CHAPTER 3

Plotting

3.1 Visualising the planet

Spiderman provides a few different ways to visualise the resulting brightness distribution on the planet, below are some examples, after the planet has been specified with “spider_params”

The “plot_planet” method outputs the visible face of the planet at the specified time (t), using the same code that is used internally for calculating the model output. This can be a useful sanity check of what the model is doing.

By default the plot will be in a standard white theme suitable for inclusion in papers or printouts, alternatively a snazzy black theme more suited to powerpoint presentations can be selected for all spiderman plots by setting the “theme” keyword to black:

Note that to save figures like this, you will have to let matplotlib know that you want to to output the figure with a black background, e.g.

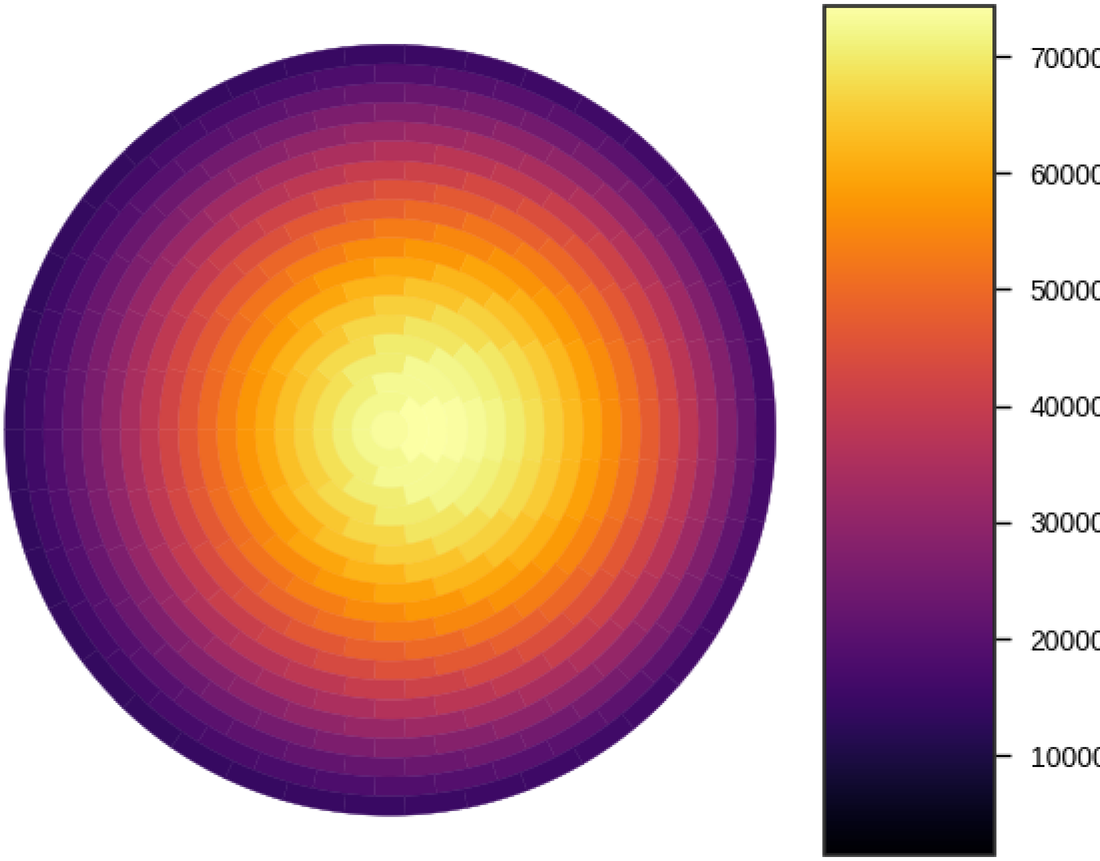
For brightness temperature based models like the Zhang model, you can also plot in temperature by setting “use_temp” to true

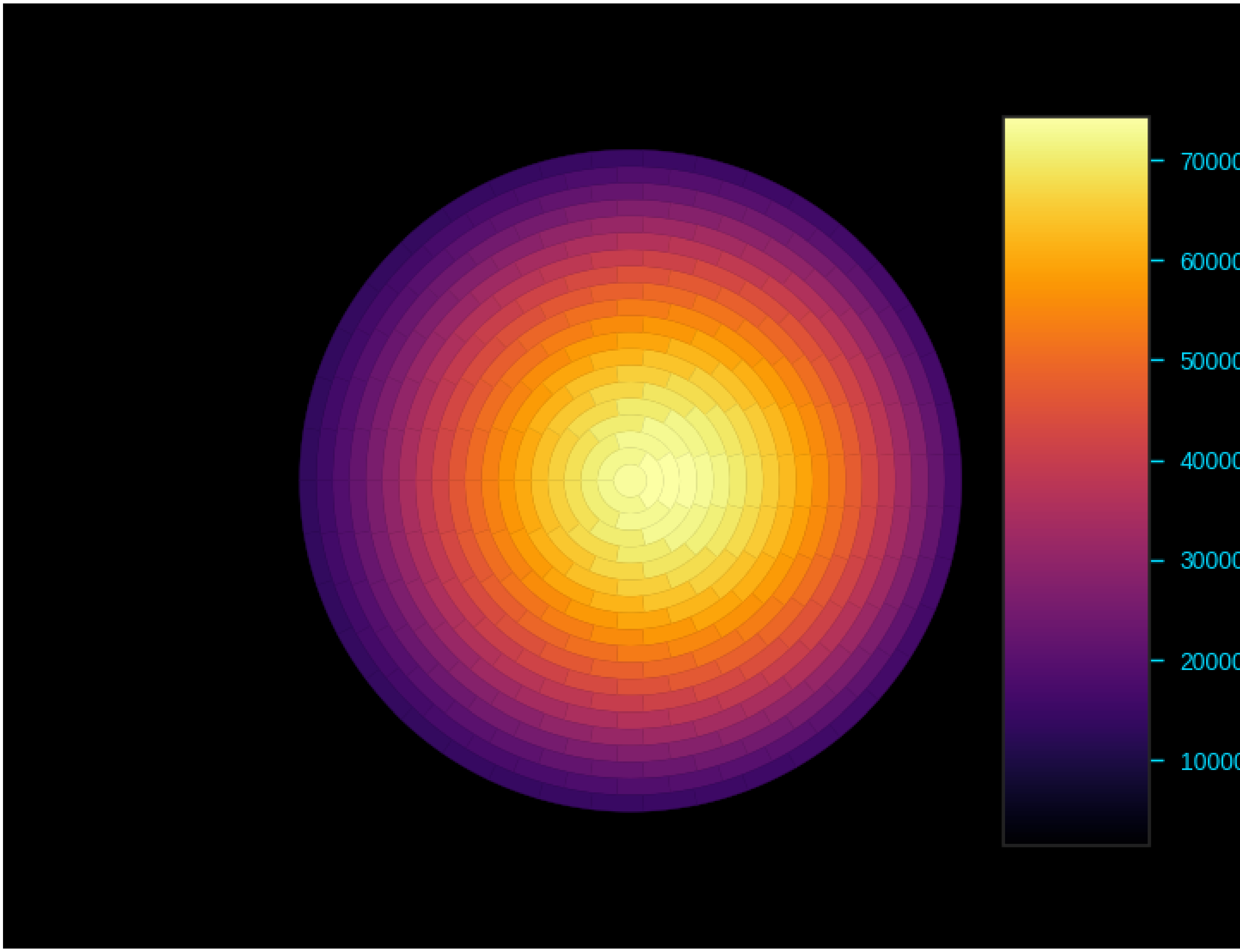
To see the system in context, you can also output a “system plot” which shows the projected position of the planet to scale with the star. Again, this plot is constructed from the same code used internally for model calculation, so is a good way to check what’s going on. Both plot_planet and plot_system can accept a phase instead of a time when the use_phase keyword is set to True

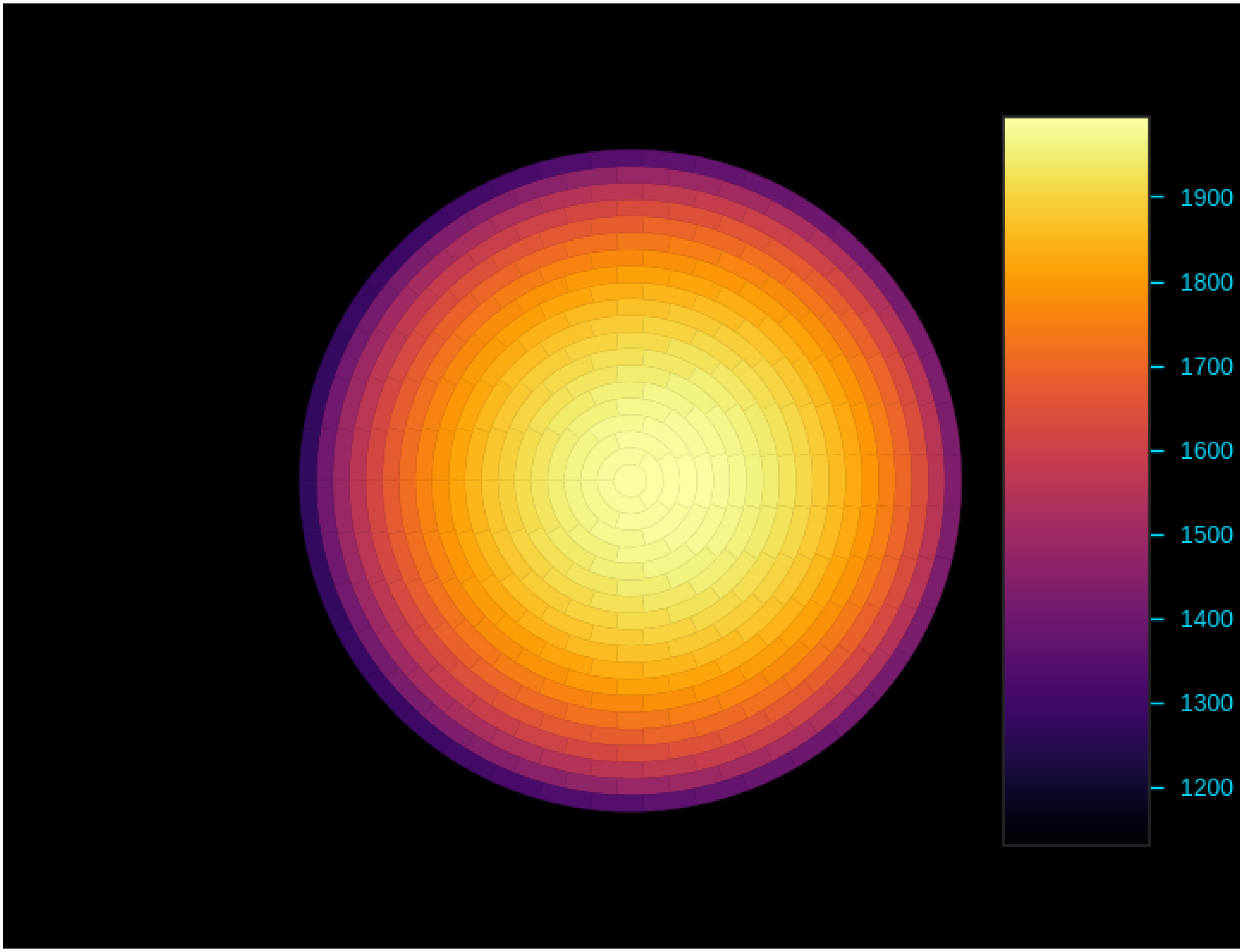
“Quad_plot” gives you a quick way to see the projected appearence of the planet at primary and secondary eclipses, and at phase 0.25 and 0.75. It has the same theming options and is able to plot either flux or temperature.

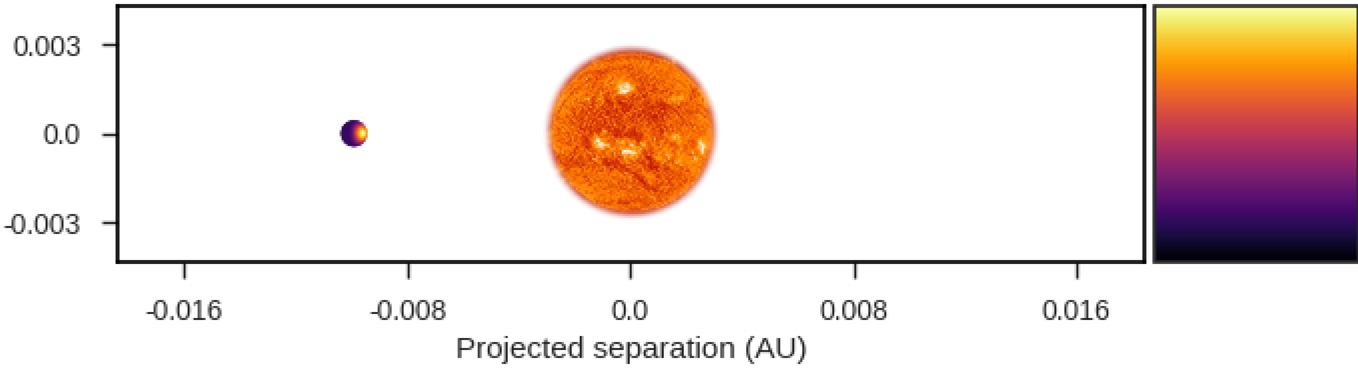
Sometimes you just want a straightforward global map - in spiderman this is generated by the “square_plot” command. This function does not use the typical spiderman segment scheme, and instead evaluates the brightness function on an evenly spaced grid in longitude and latitude. The number of grid points in the latitude and longitude direction are specified by nla and nlo keywords, respectively.

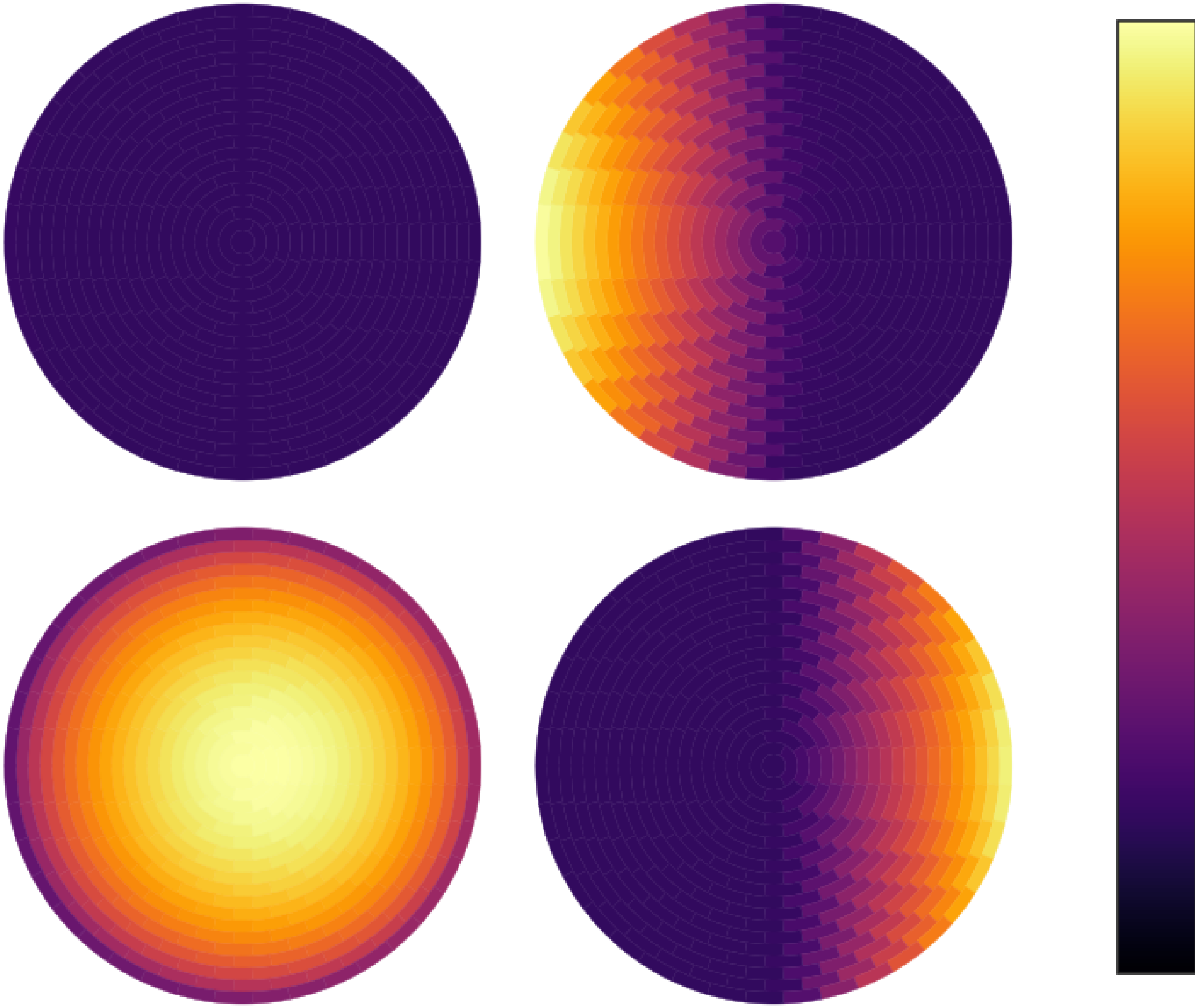
end

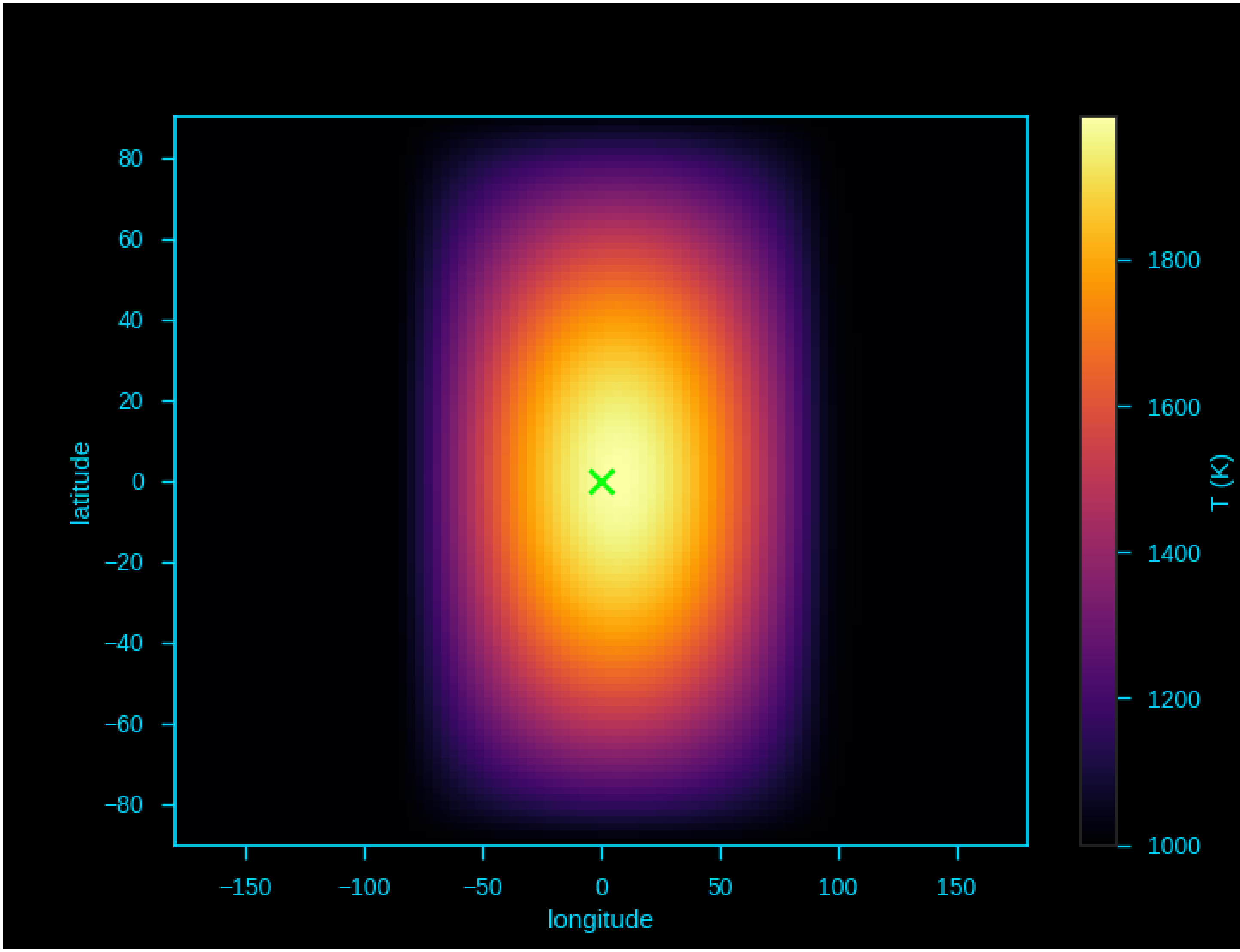

70000
60000
50000
40000
30000
20000
10000


70000
60000
50000
40000
30000
20000
10000


1900
1800
1700
1600
1500
1400
1300
1200


0.003
0.0
-0.003
-0.016
-0.008
0.0
0.008
0.016
Projected separation (AU)




80
60
40
20
0
−20
−40
−60
−80
latitude
−150
−100
−50
0
50
100
150
longitude
1800
1600
1400
1200
1000
T (K)

3.2 Generating a simple spectrum

Sometimes you don’t want to bother with running a full orbital model, and just want a quick estimate of the eclipse depth of system. Spiderman has a couple of techniques to allow you to do this.

If all you want is the eclipsed depth, you can use the “eclipse_depth” method, like so:

```
import spiderman as sp
import numpy as np
import matplotlib.pyplot as plt

spider_params = sp.ModelParams(brightness_model='zhang')
spider_params.n_layers = 5
```

for this example we’ll use a Zhang and Showman type model with 5 layers, next the relevent model parameters are entered -

```
spider_params.l1 = 1.1e-6       # The starting wavelength in meters
spider_params.l2 = 1.7e-6       # The ending wavelength in meters

spider_params.T_s = 4520
spider_params.rp = 0.159692

spider_params.xi = 0.1
spider_params.T_n = 1000
spider_params.delta_T = 1000
```

Note that if all you want is a simple eclipse depth, there’s no need to enter the orbital parameters. Spiderman will assume a circular orbit and an inclination of 90 degrees unless you tell it otherwise. Now, you can call the eclipse_depth:

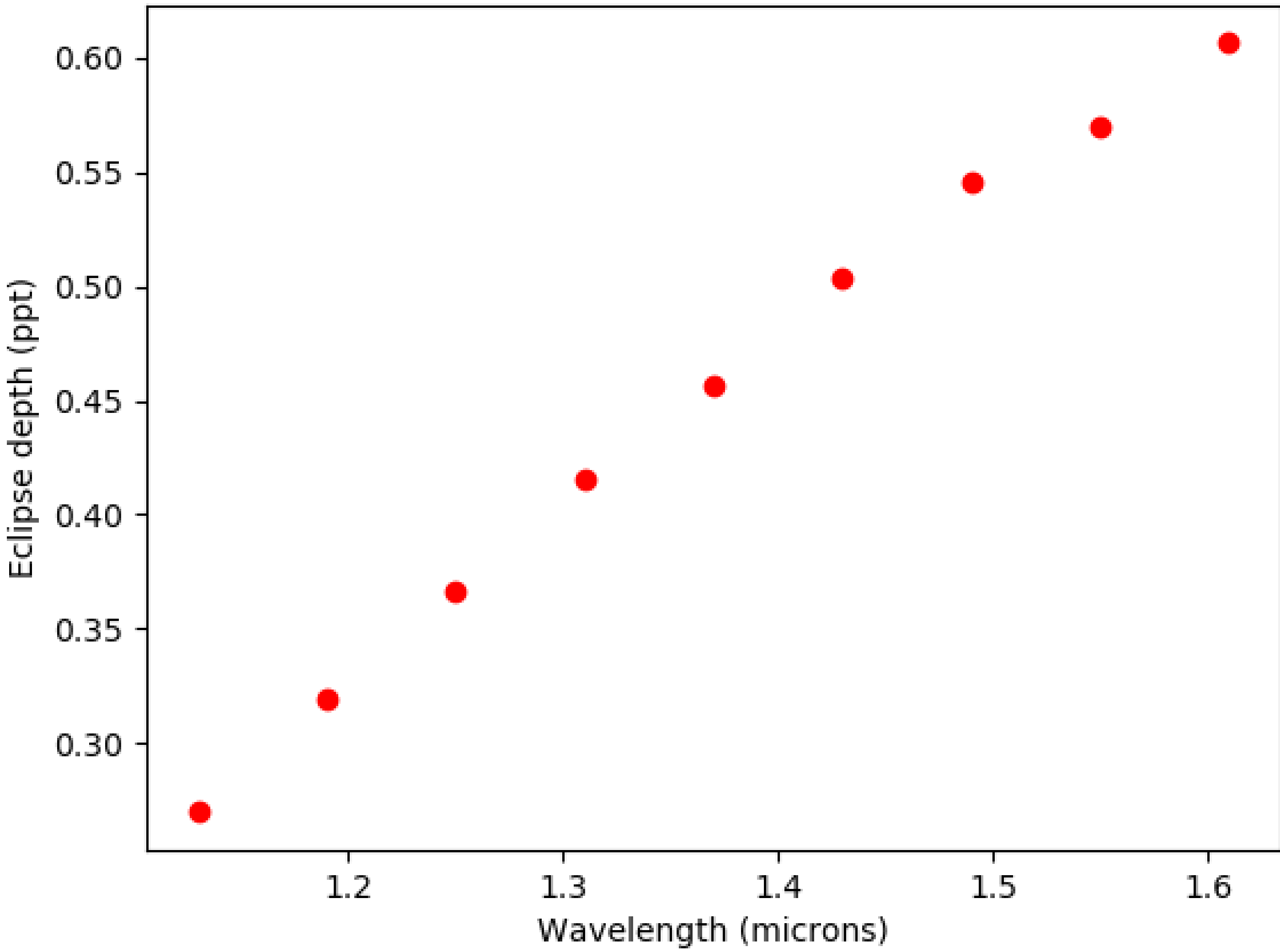
```
d = spider_params.eclipse_depth()
print(d)
>> 0.00045781826310942186
```

This method can be used to quickly generate an occultation spectrum of the depth as a function of wavelength, like so:

```
min_wvl = 1.1e-6
max_wvl = 1.7e-6
steps = 10
wvl_step = (max_wvl-min_wvl)/steps

for i in range(0,steps-1):
        spider_params.l1 = min_wvl + wvl_step*i
        spider_params.l2 = min_wvl + wvl_step*(i+1)

        mid_wvl = min_wvl + wvl_step*(i+0.5)
        d = spider_params.eclipse_depth()
        plt.plot(mid_wvl*1e6,d*1000,'ro')

plt.xlabel('Wavelength (microns)')
plt.ylabel('Eclipse depth (ppt)')
```

Some caution must be used with this method, as it only returns the *blocked light* relative to the stellar brightness at the specified phase - so for an example, if you were to specify a grazing transit you would not recieve the total flux of the dayside.

If you do want the total flux of the planet from a specific phase, you can instead use the “phase_brightness” method. Using this method you can calulate the emission spectrum of the planet in *physical units* at the phase of your choosing,


0.60
0.55
0.50
0.45
0.40
0.35
0.30
Eclipse depth (ppt)
1.2
1.3
1.4
1.5
1.6
Wavelength (microns)

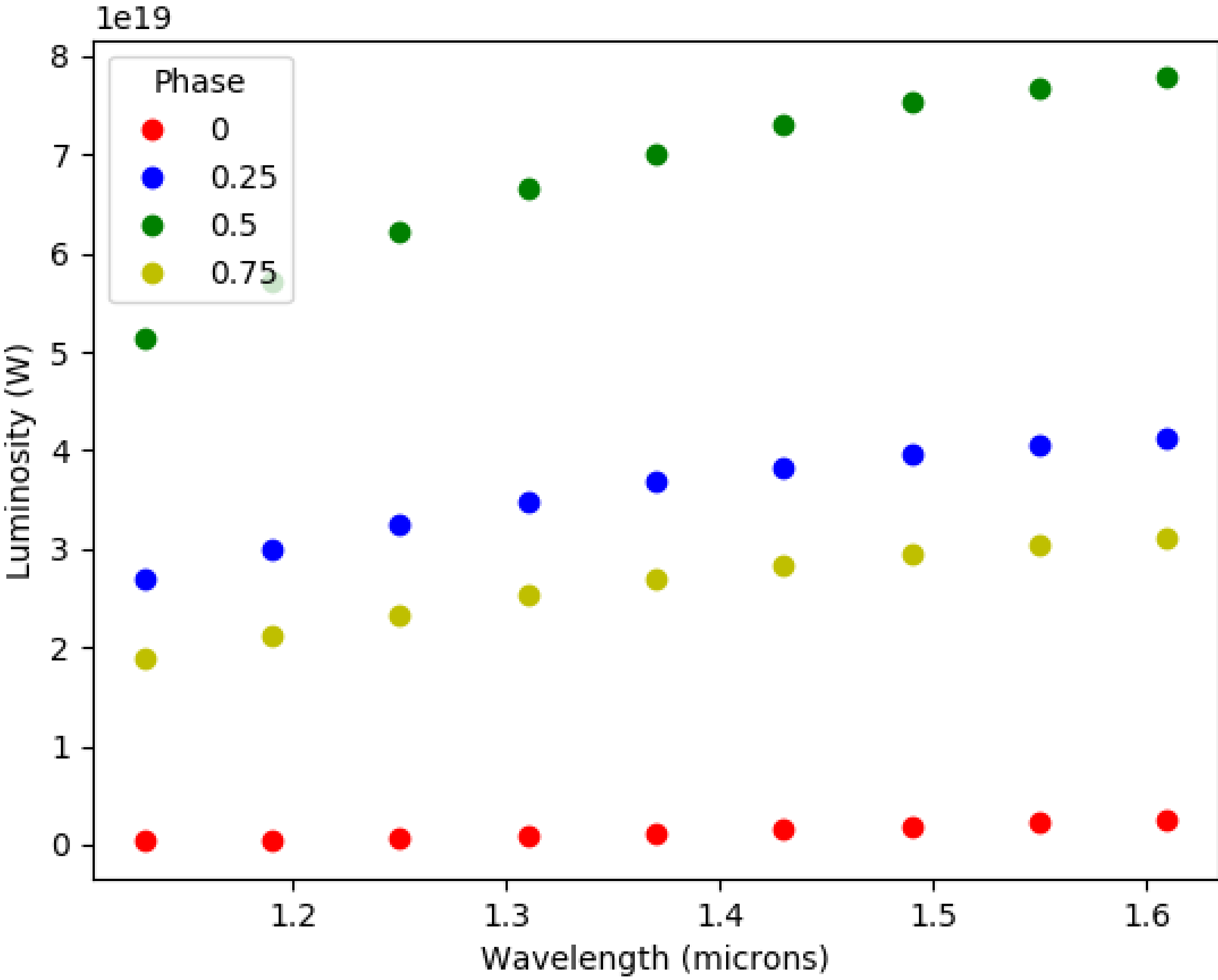
it is called in a similar way to eclipse_depth, but has an optional phase argument which can accept either a single phase value or a list. You can provide a planet radius to recieve the total band luminosity of the visible hemisphere in Watts, if this is not given then an average surface intensity will be returned.

```
mid_wvls = []
p1s = []
p2s = []
p3s = []
p4s = []

for i in range(0,steps-1):
        spider_params.l1 = min_wvl + wvl_step*i
        spider_params.l2 = min_wvl + wvl_step*(i+1)

        mid_wvl = min_wvl + wvl_step*(i+0.5)
        mid_wvls += [mid_wvl*1e6]

        p1, p2, p3, p4 = spider_params.phase_brightness([0.0,0.25,0.5,0.75],planet_
↪radius=6.9911e7)

        p1s += [p1]
        p2s += [p2]
        p3s += [p3]
        p4s += [p4]

plt.plot(mid_wvls,p1s,'ro',label = '0')
plt.plot(mid_wvls,p2s,'bo',label = '0.25')
plt.plot(mid_wvls,p3s,'go',label = '0.5')
plt.plot(mid_wvls,p4s,'yo',label = '0.75')


plt.legend(title='Phase')
plt.xlabel('Wavelength (microns)')
plt.ylabel('Luminosity (W / sr)')
```

Finally, you can use the total_luminosity method to return the total band luminosity of the planet in the model in Watts, a planet radius in meters is required:

```
spider_params.l1 = 1.1e-6
spider_params.l2 = 1.7e-6
lum = spider_params.total_luminosity(10*6.9911e7)
print(lum)
>> 7.03802421799e+20
```

end.


1e19
8
7
6
5
4
3
2
1
0
Luminosity (W)
Phase
0
0.25
0.5
0.75
1.2
1.3
1.4
1.5
1.6
Wavelength (microns)

CHAPTER 4

Brightness maps

4.1 Spherical Harmonics

A spherical harmonics model, the user can specify the co-eficients for as many terms as desired. Spherical harmonics models are useful, since they do not make any physical assumptions about the distribution you wish to recover. It can be useful to check the results of a physically motivated model against the results of a spherical harmonic fit. Called with “spherical”.

main parameters:

degree The maximum degree of Harmonic you want to consider (You won’t typically want more than 2)

la0 Offset of the center of the co-ordinte centre from the substellar point in the latitude direction (unit: Degrees)

lo0 Offset of the center of the co-ordinte centre from the substellar point in the longitude direction (unit: Degrees)

sph A list of the co-efficients for the harmonic terms, there *must* be the appropriate number (degree squared), and arranged in the correct order: [l0, l1 m-1, l1 m0, l1 m1, l2 m-2, l2 m-1, l2 m0, l2 m1, l2 m2….. etc]. These parameters are scaled to be relative to the stellar flux, so will typically be of order 1e-3 - 1e-4.

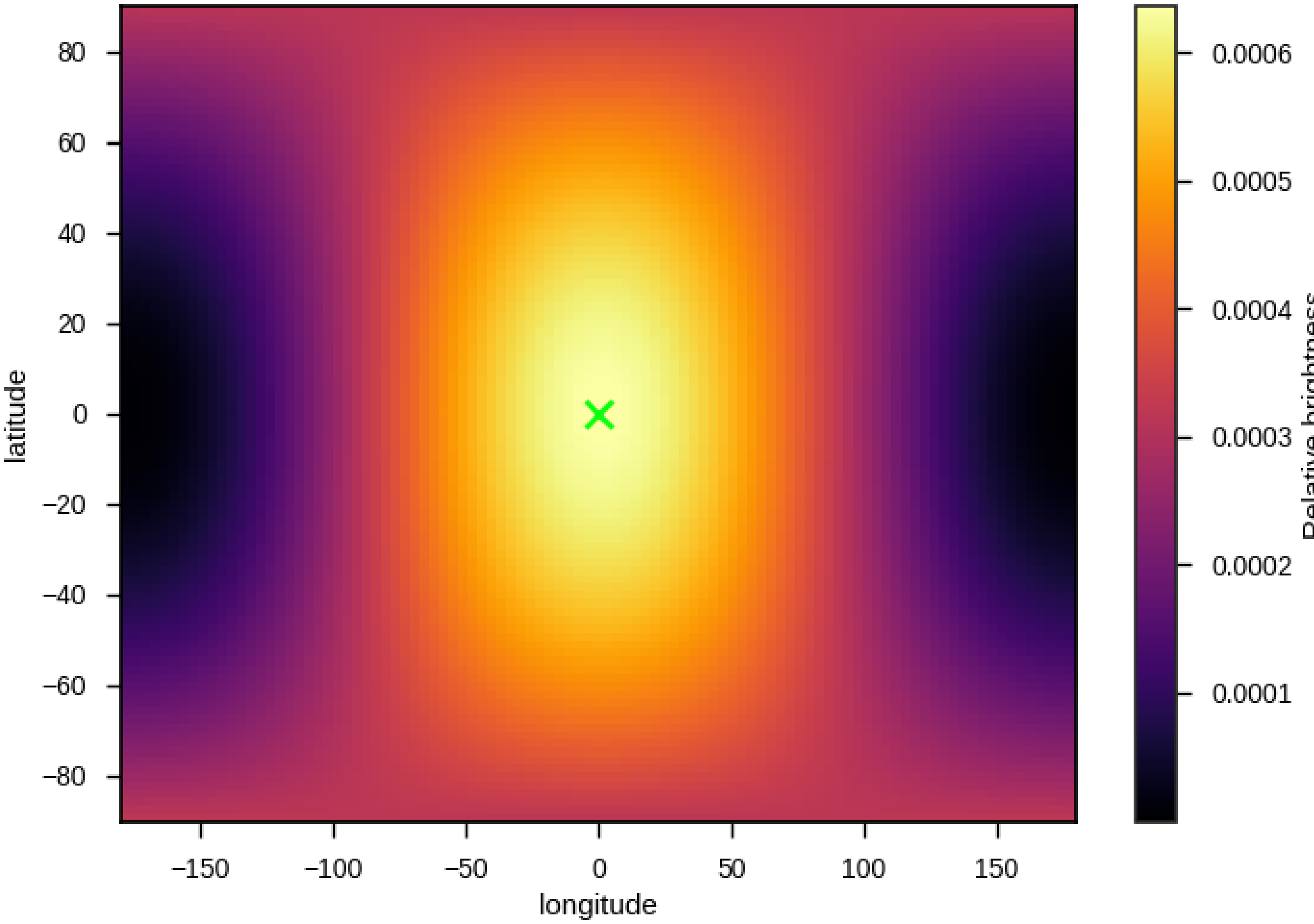
> **Warning:** There is nothing implicit in this spherical harmonics implementation to prevent negative surface fluxes! It is suggested that care is taken when specifying priors to prevent unphysical results.

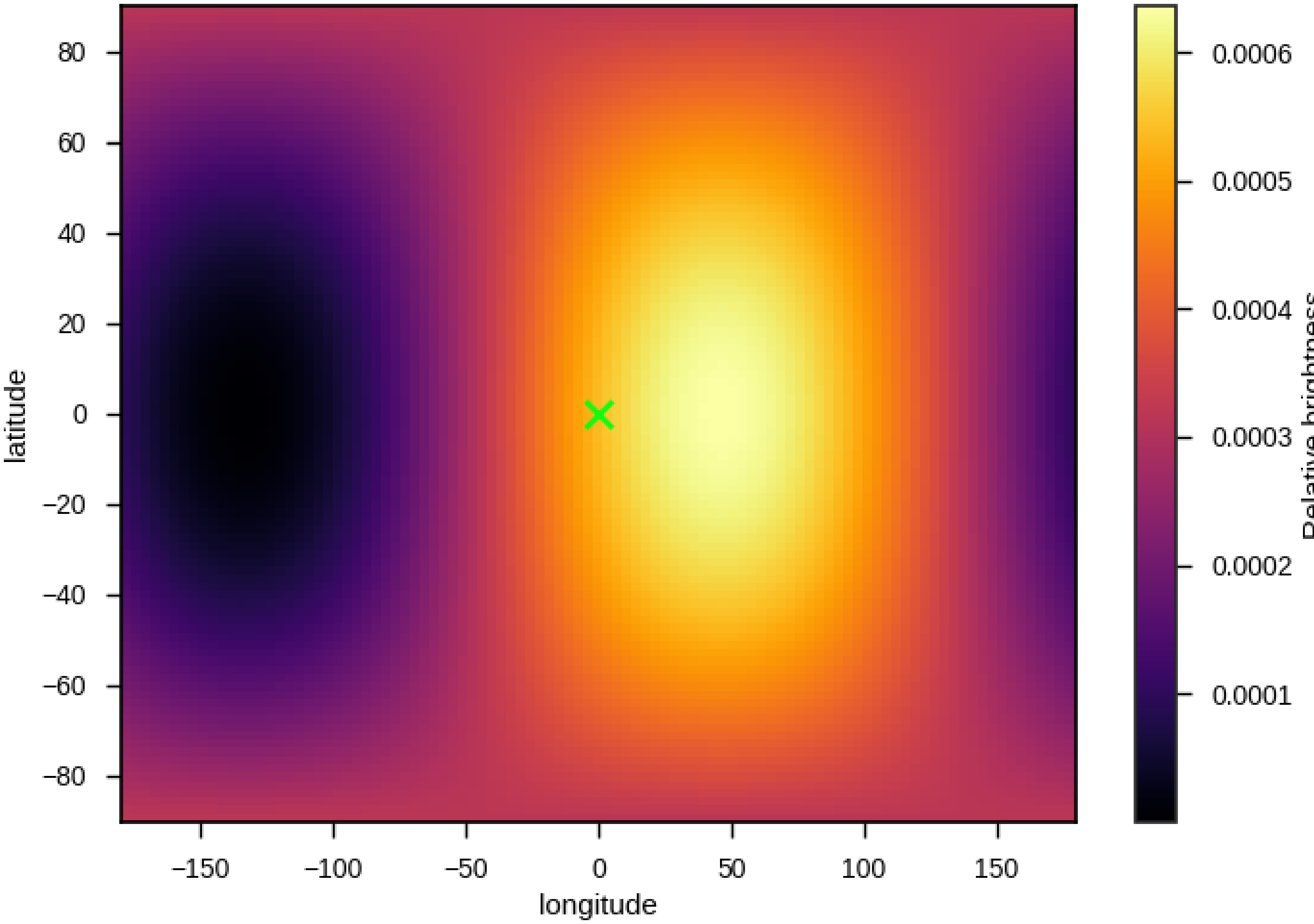
An example square plot using a two degree spherical harmonic using the l0 m0 and l1 m1 terms only - this is a simple dipole, and can represent a day/night side difference:

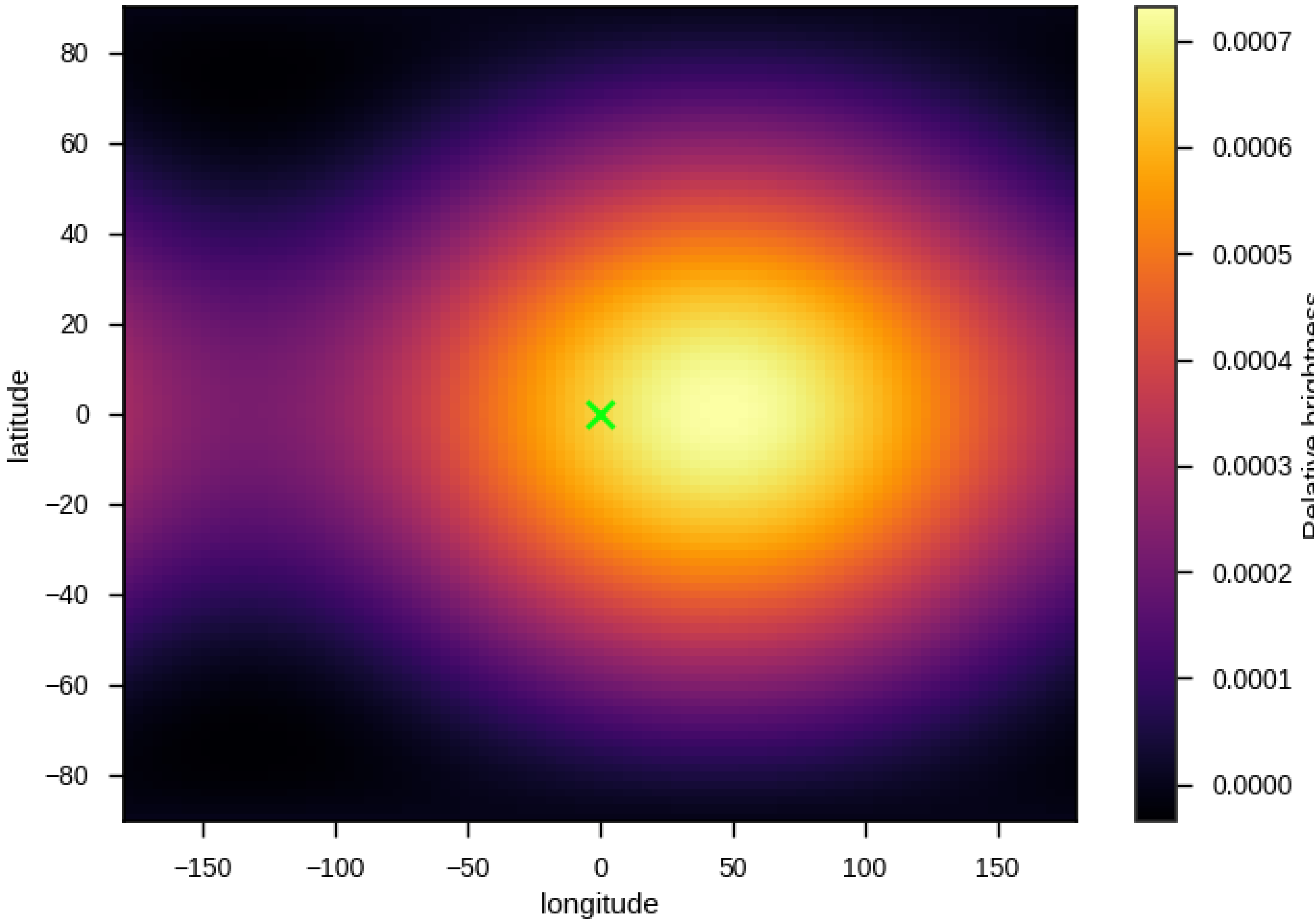
This time the hotspot is offset by adding the l1 m-1 term. (the same effect can also be achieved by changing the la0 and lo0 parameters, but never try to fit for both simultaneously, as it’s degenerate!):

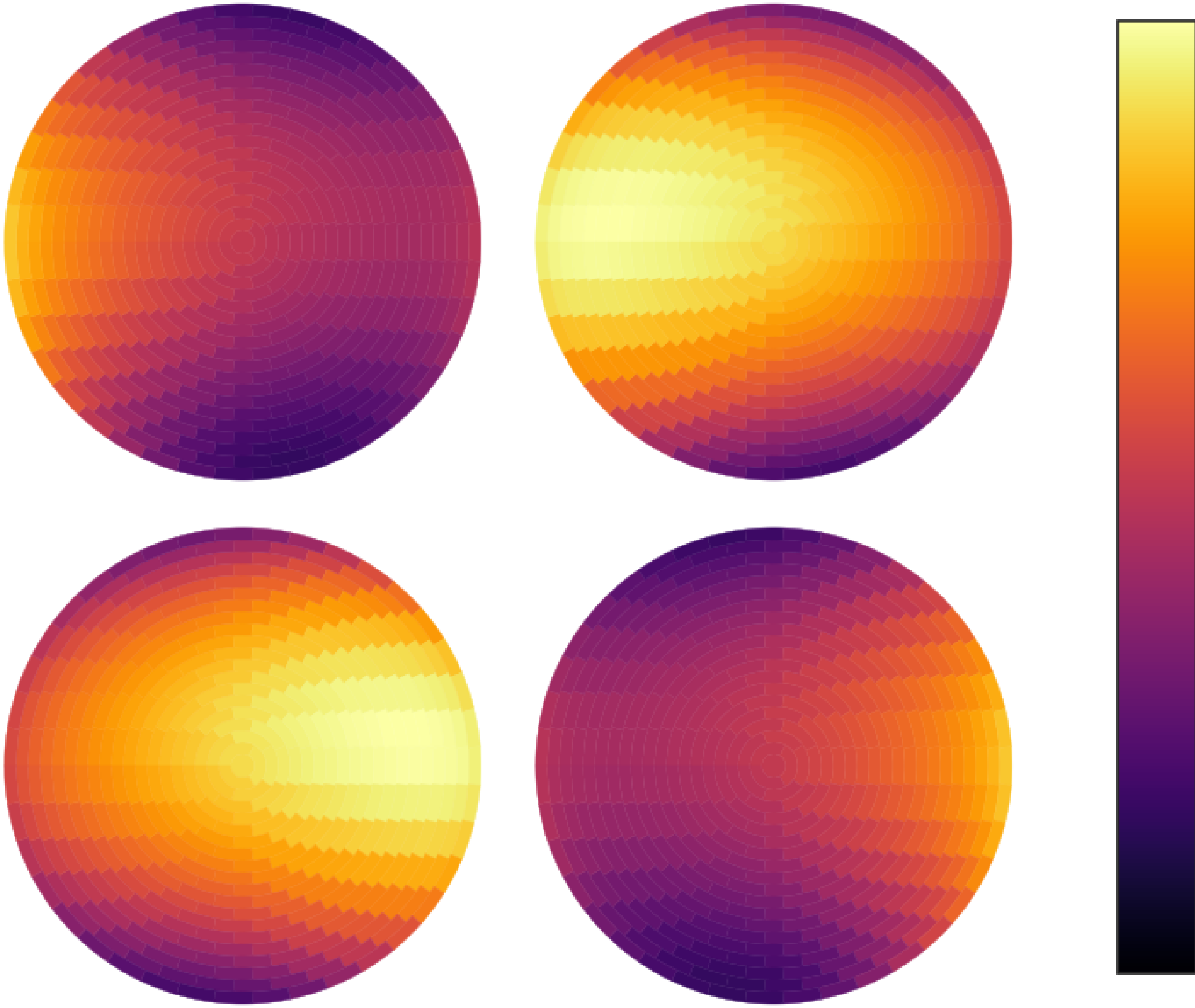
Now, with a higher order term added, l2 m0, to concentrate flux towards the equator.

An example four phase plot with this distribution:

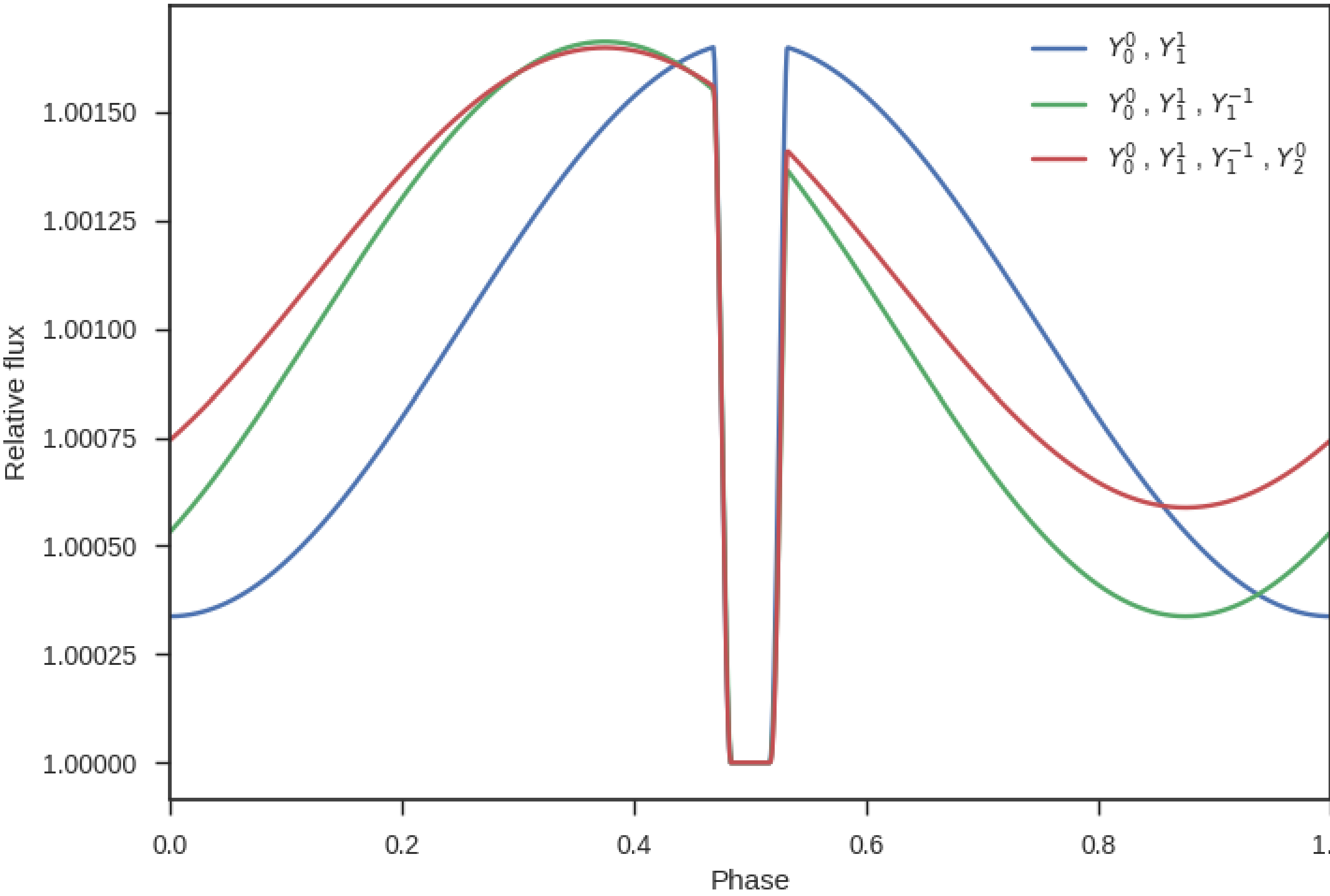

80
60
40
20
0
−20
−40
−60
−80
latitude
−150
−100
−50
0
50
100
150
longitude
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
Relative brightness


80
60
40
20
0
−20
−40
−60
−80
latitude
−150
−100
−50
0
50
100
150
longitude
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
Relative brightness


80
60
40
20
0
−20
−40
−60
−80
latitude
−150
−100
−50
0
50
100
150
longitude
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
Relative brightness



The resulting lightcurves for the three example distributions:



4.2 Zhang and Showman 2017

A temperature map based on the equations given in the appendix of Zhang and Showman 2017 (http://adsabs.harvard.edu/abs/2017ApJ...836...73Z) This semi-physical model well reproduces the main features of hot Jupiter phase-curves - offset hotspots. Called with "zhang"

main parameters:

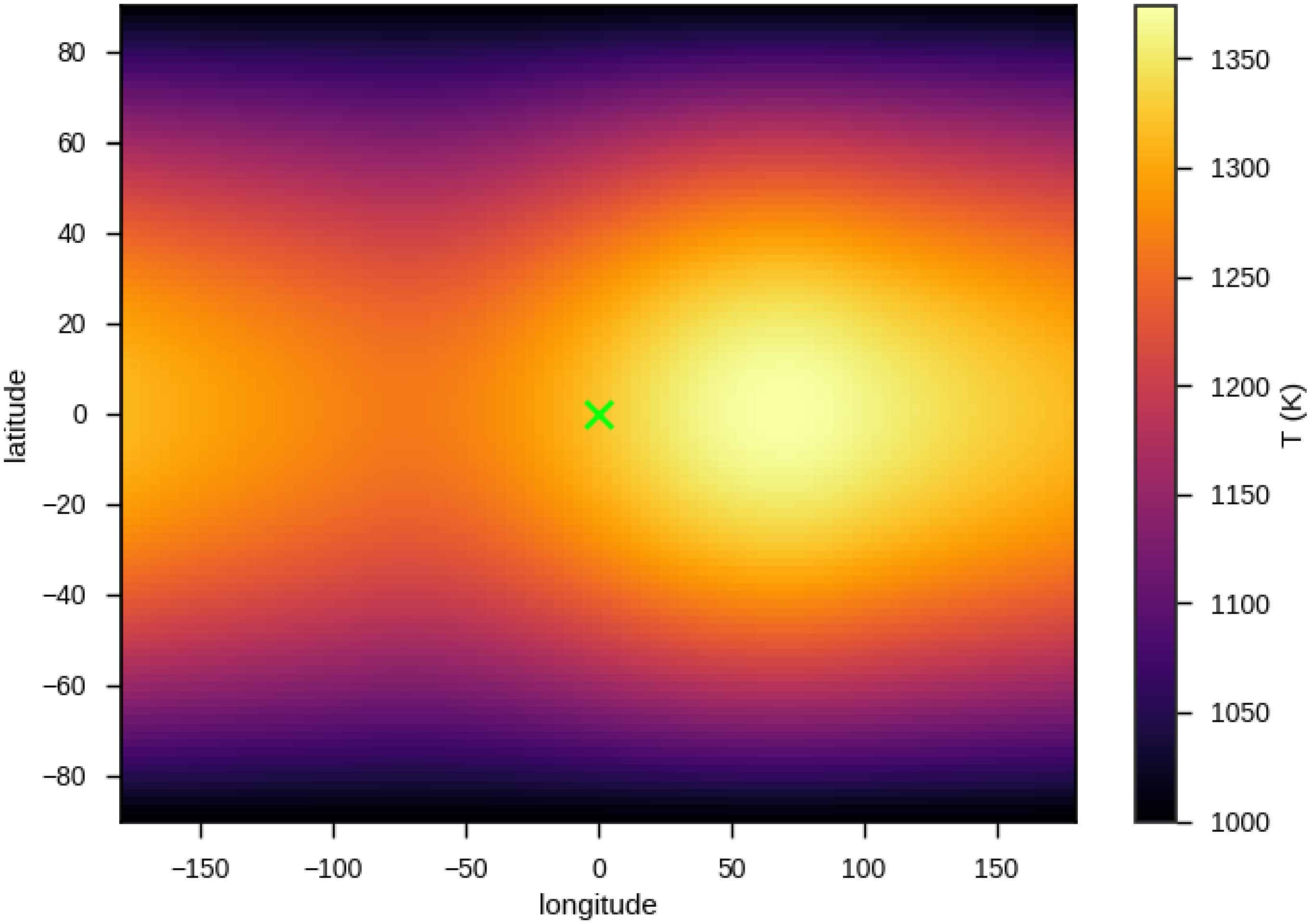
xi Ratio of radiative to advective timescale (unit: Unitless)

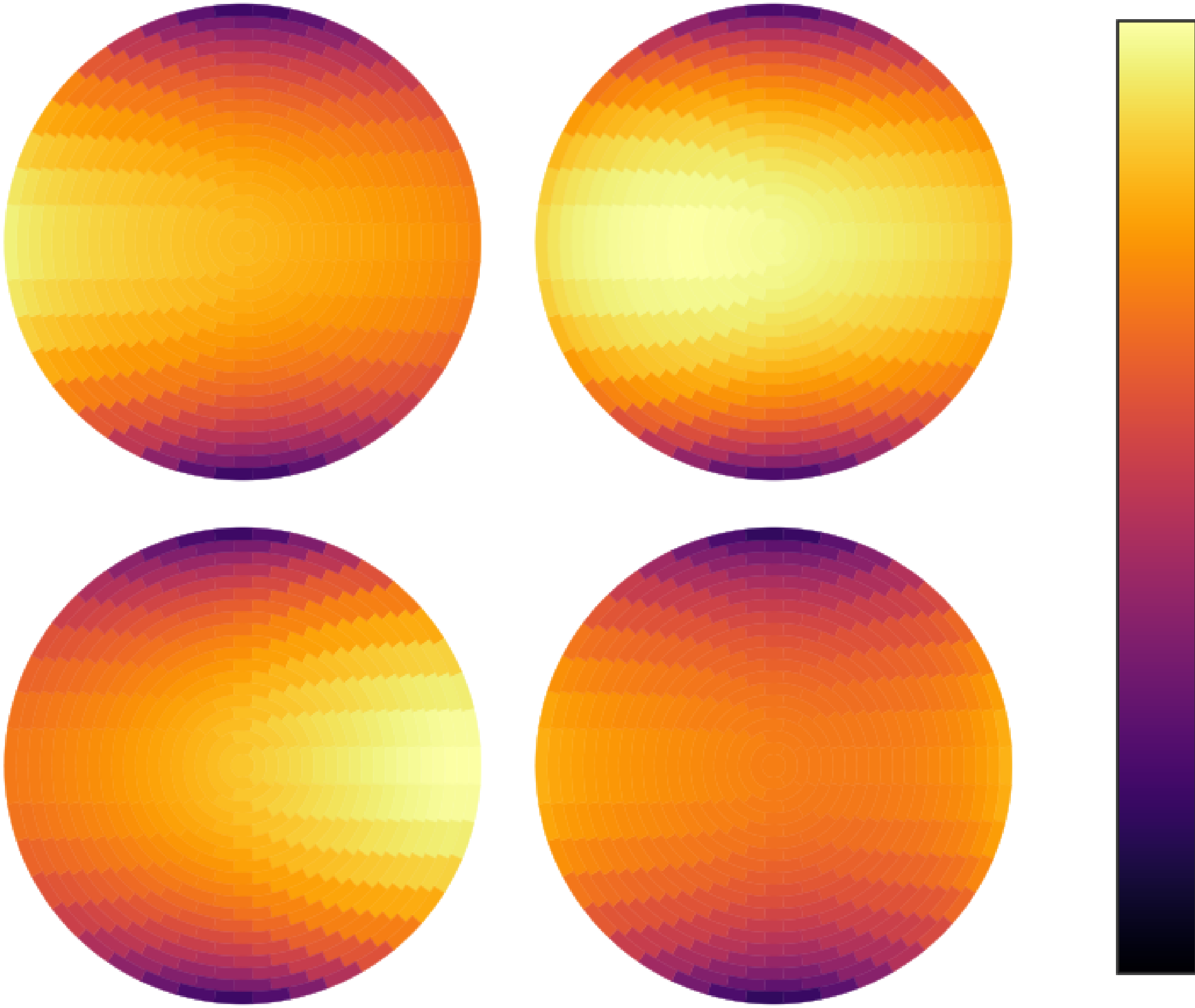
T_n Temperature of the nightside of the planet (unit: Kelvin)

delta_T Day-night temperature contrast (unit: Kelvin)

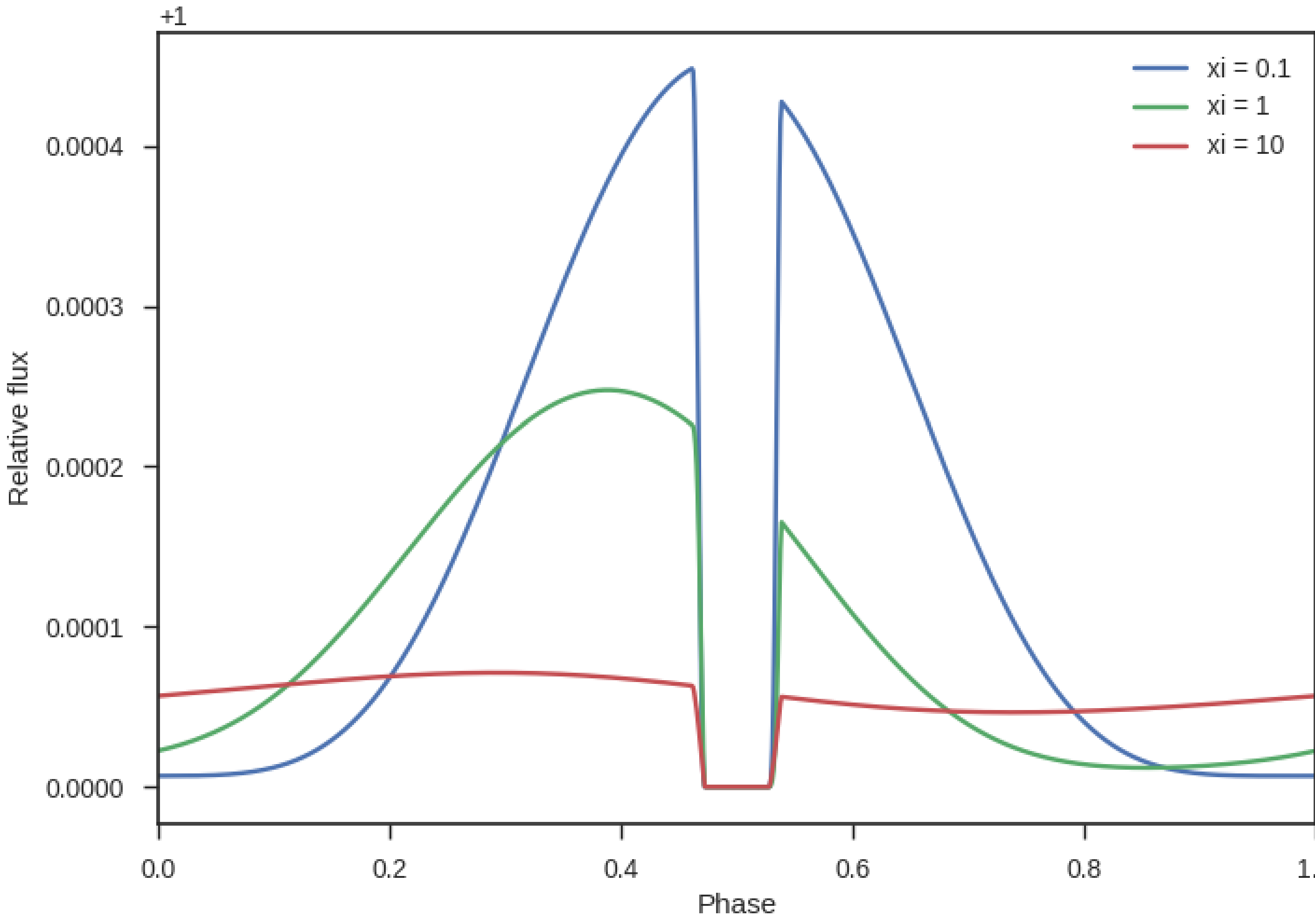
An example square plot:

An example four phase plot:


80
60
40
20
0
−20
−40
−60
−80
latitude
−150
−100
−50
0
50
100
150
longitude
1350
1300
1250
1200
1150
1100
1050
1000
T (K)



The resulting lightcurves for several parameter values



4.3 Offset hotspot

main parameters:

la0 Offset of the center of the hotspot in the latitude direction (unit: Degrees)

lo0 Offset of the center of the hotspot in the longitude direction (unit: Degrees)

size The radius of the hotspot in degrees, i.e., 90 means the hotspot covers a whole hemisphere. (unit: degrees)

The hotspot can either be specified as "hotspot_b", to directly specify the fractional brightness, in which case these parameters are used:

spot_b The surface brightness of the hotspot as a fraction of the surface brightness of the star, typically of order ~1e-4 for hot Jupiters (unitless)

p_b The surface brightness of the planet that is not in the hotspot as a fraction of the surface brightness of the star. This value will depend strongly on the physics of heat transport in the planets atmosphere and may be several orders of magnitude fainter than the spot (unitless)

Or as “hotspot_t” to specify in terms of brightness temperature, in which case the following parameters are used instead. In this case the wavelength range to integrate over must be specified.

spot_T The surface brightness of the hotspot as a fraction of the surface brightness of the star, typically of order ~1e-4 for hot Jupiters (unitless)

p_T The brightness temperature of the planet that is not in the hotspot as a fraction of the surface brightness of the star. This value will depend strongly on the physics of heat transport in the planets atmosphere and may be several orders of magnitude fainter than the spot (unitless)

Note: Because there is a sharp contrast in flux levels between *spot* and *not spot* regions, this brightness model can have issues with quantisation, which produces unphysical “steps” in the lightcurve. This can be for the time being be solved by including a numerical integration step in regions with sharp contrasts with the optional paramter “grid_size”

cont

grid_size This model has a sharp boundary, so can have quantization issues. Regions with sharp changes in brightness are for now integrated numerically instead of analytically, this sets the number of grid points to use in the integration along each direction, to the total number of additional function calls will be this value squared. Setting this too high can significantly slow the code down, however if it is too low fits may be numerically unstable. Use caution. This is a temporary fix and is intended to be removed in a future version (default: 10)

An example square plot:

An example four phase plot:

The resulting lightcurves for several parameter values

4.4 Two sided planet

This is a simple model that only assumes that the day-side of the planet has a different flux or temperature to the night side. can be called as “two temperature” to specify with brightness temperature, or “two brightness” to secify by flux

main parameters:

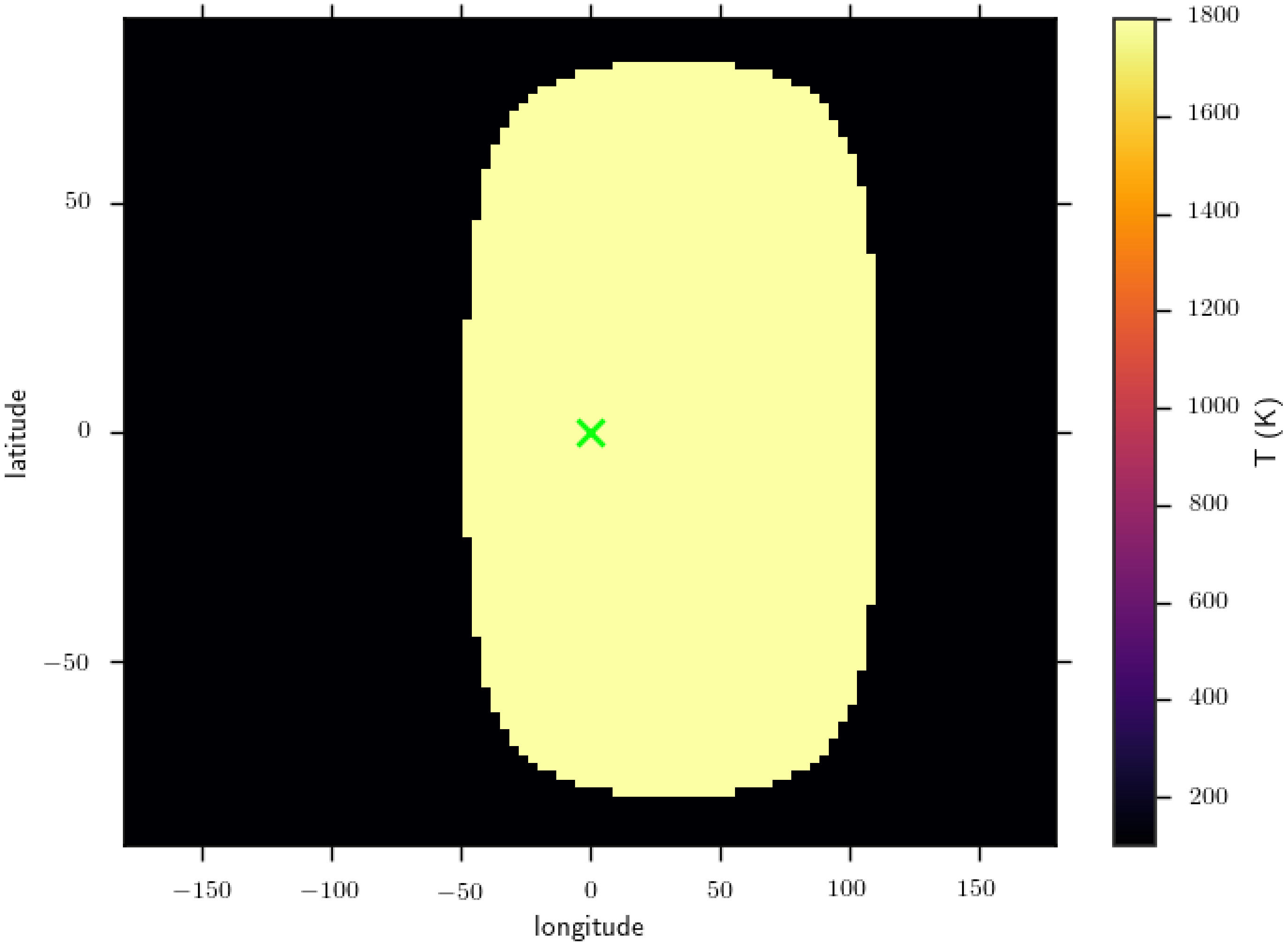
The hotspot can either be specified as “hotspot_b”, to directly specify the fractional brightness, in which case these parameters are used:

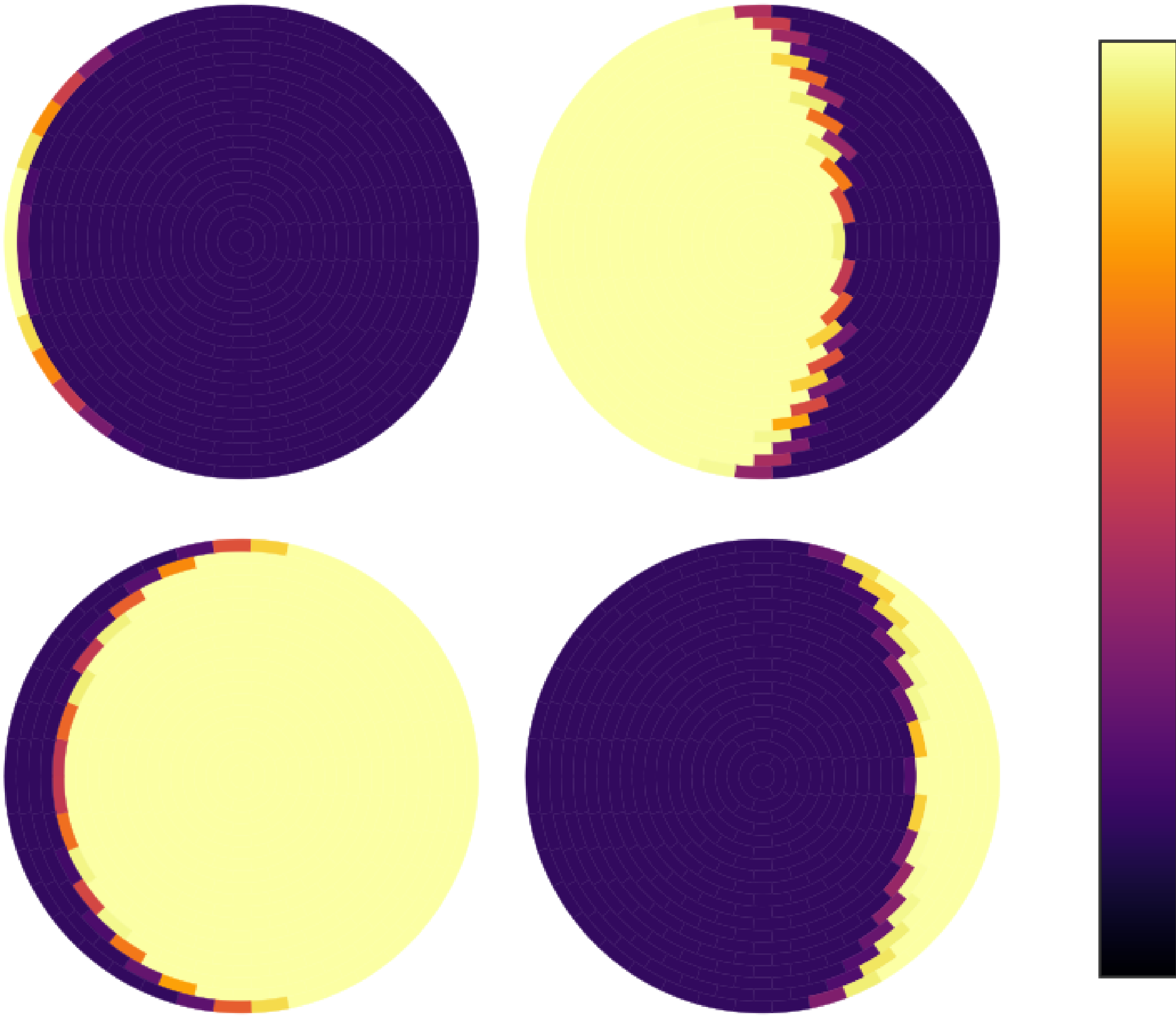
pb_d The surface brightness of the dayside as a fraction of the surface brightness of the star, typically of order ~1e-4 for hot Jupiters (unitless)

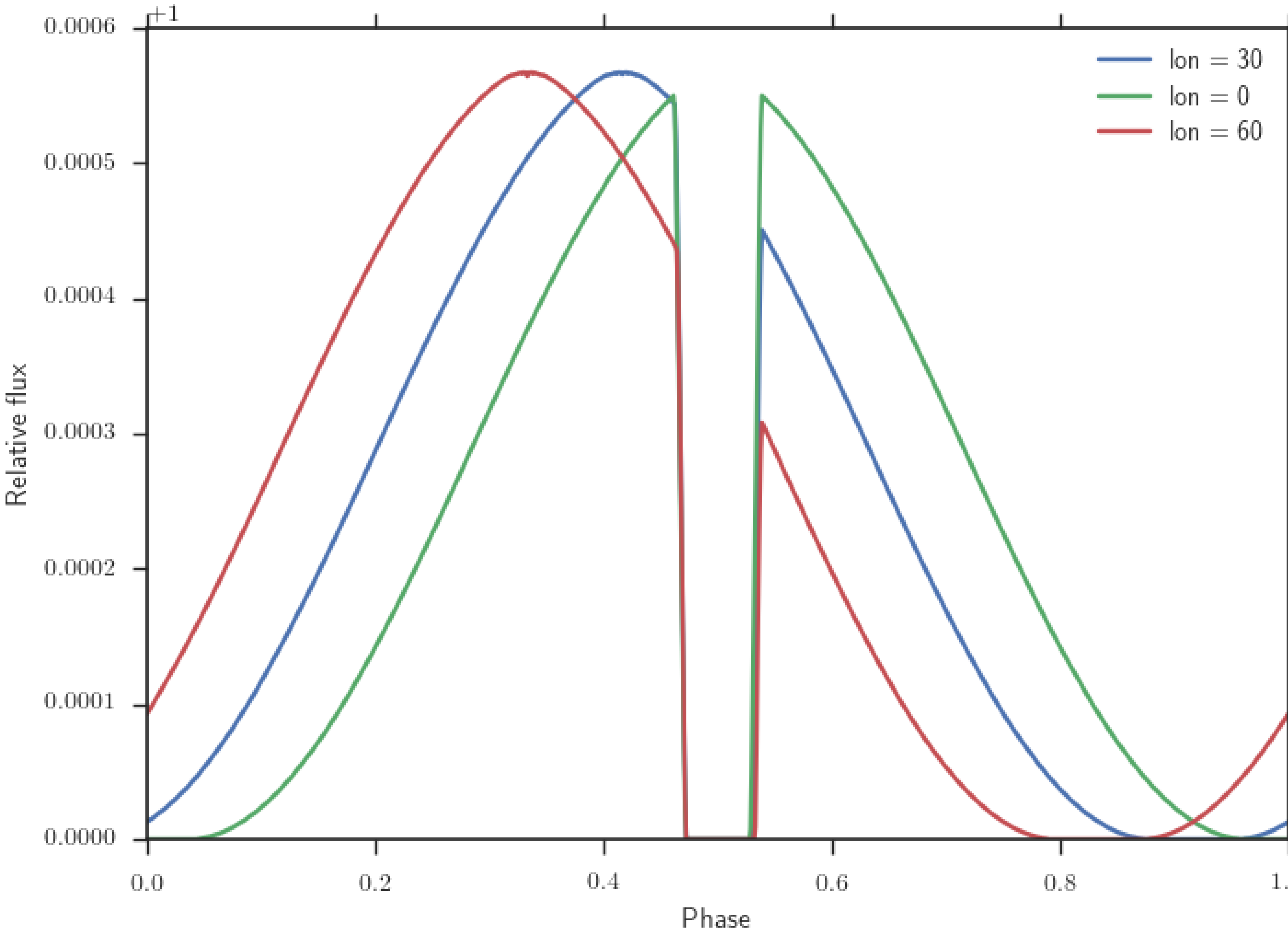
pb_n The surface brightness of the planet nightside as a fraction of the surface brightness of the star. This value will depend strongly on the physics of heat transport in the planets atmosphere and may be several orders of magnitude fainter than the spot (unitless)

Or as “hotspot_t” to specify in terms of brightness temperature, in which case the following parameters are used instead. In this case the wavelength range to integrate over must be specified.

spot_T The surface brightness of the hotspot as a fraction of the surface brightness of the star, typically of order ~1000 K for hot Jupiters (unit: kelvin)


latitude
50
0
−50
−150
−100
−50
0
50
100
150
longitude
1800
1600
1400
1200
1000
800
600
400
200
T (K)




+1
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
Relative flux
0.0
0.2
0.4
0.6
0.8
1.
Phase
lon = 30
lon = 0
lon = 60

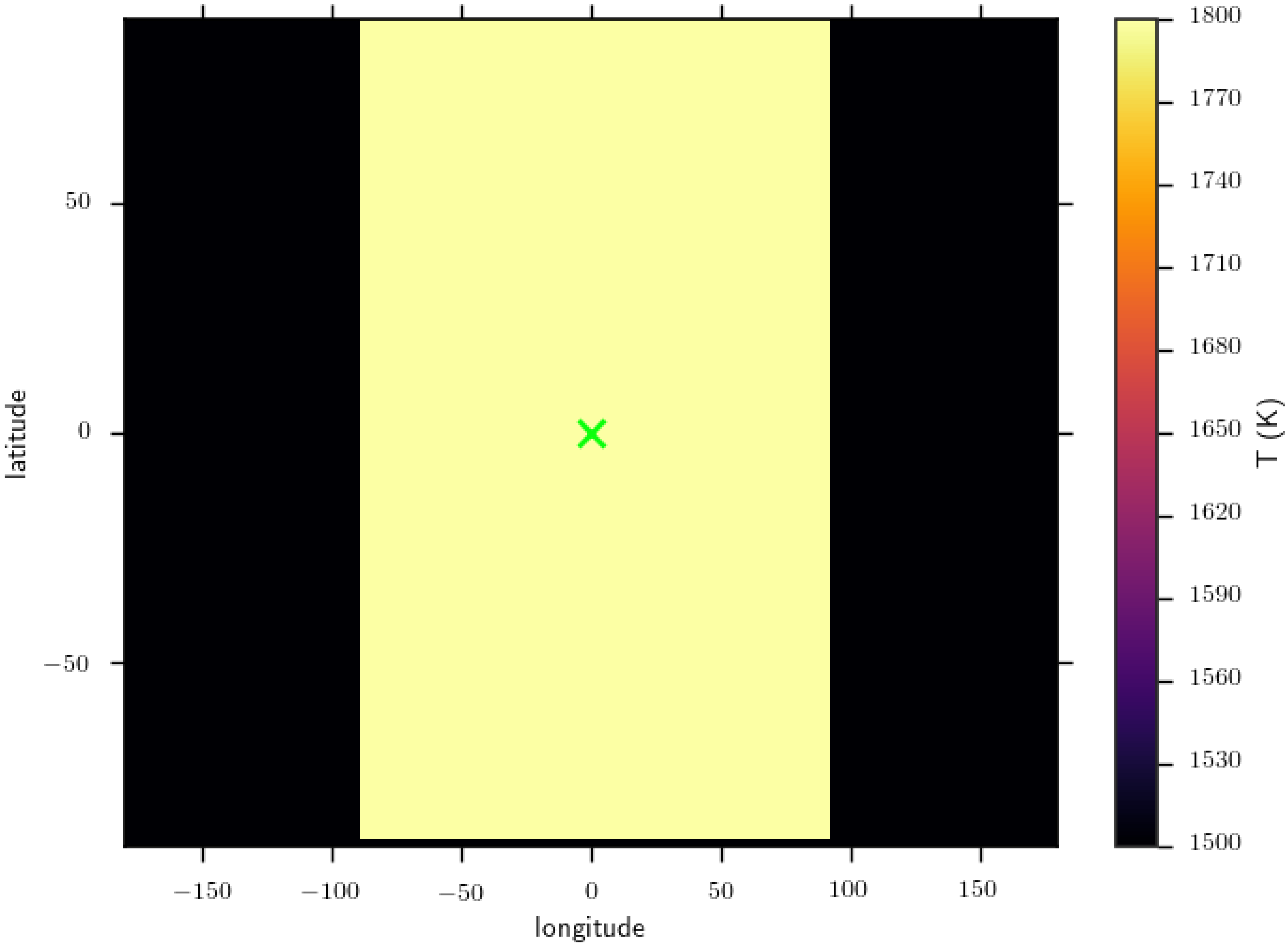
p_T The brightness temperature of the planet that is not in the hotspot. This value will depend strongly on the physics of heat transport in the planets atmosphere and may be significantly cooler than the spot (unit: degrees)

Note: Because there is a sharp contrast in flux levels between *spot* and *not spot* regions, this brightness model can have issues with quantisation, which produces unphysical "steps" in the lightcurve. This can be for the time being be solved by including a numerical integration step in regions with sharp contrasts with the optional paramter "grid_size"

cont

grid_size This model has a sharp boundary, so can have quantization issues. Regions with sharp changes in brightness are for now integrated numerically instead of analytically, this sets the number of grid points to use in the integration along each direction, to the total number of additional function calls will be this value squared. Setting this too high can significantly slow the code down, however if it is too low fits may be numerically unstable. Use caution. This is a temporary fix and is intended to be removed in a future version (default: 10)

An example square plot:



An example four phase plot:

The resulting lightcurves for several parameter values

4.5 Forward model

SPIDERMAN also has the capability to take the results of forward models and project them onto a planet, to quickly generate a phase curve and secondary eclipse from your favourite model output. SPIDERMAN uses bicubic interpolation to produce smooth and neat looking results from coursely sampled grids.

main parameters:

This model is called as either "direct_b", in which case the brightness grid is expected to be specified *relative to the brightness of the star*, or as "direct_T", in which case the grid is expected as brightness temperatures and stellar Temperature and filter details will also be needed. The call parameters are:

grid A list containing the longitude and latitude axis (in degrees) and a 2d array of flux/temperature. SPIDERMAN has a tool (format_grid) to generate this grid in the correct format.

How to use "format_grid":

```
import spiderman as sp
spider_params = sp.ModelParams(brightness_model="direct_b")

### specify orbital parameters ###

spider_params.grid = sp.format_grid(lo,la,flux)
```

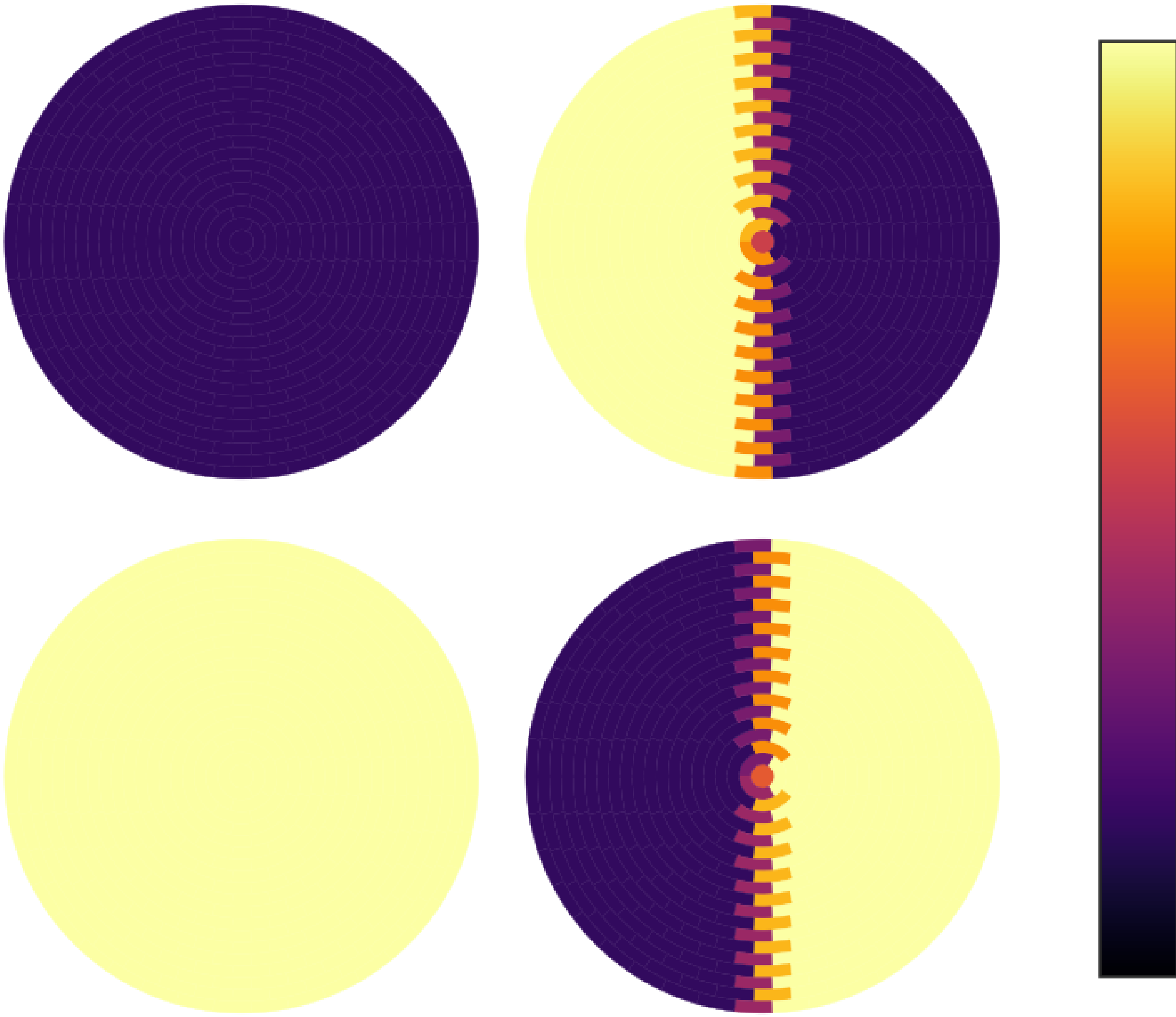
Where lo, la and flux are the longitude, latitude and flux values, which can either be given as 2d arrays or a flattened list. The dimensions **must** match.

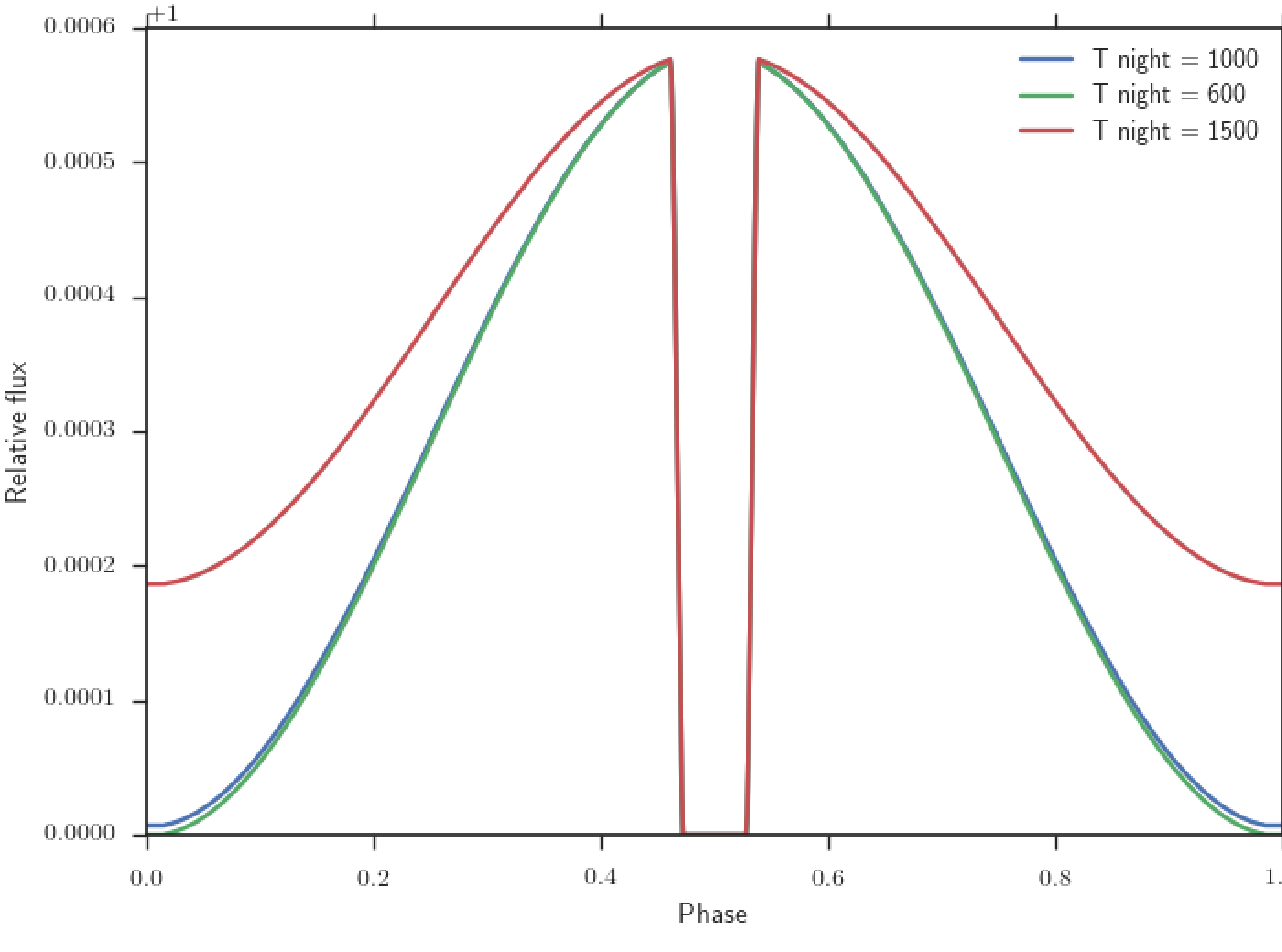
This method allows you to test any arbitrary brightness distribution, so, for example, here is a map of "SPIDERMAN-1b"

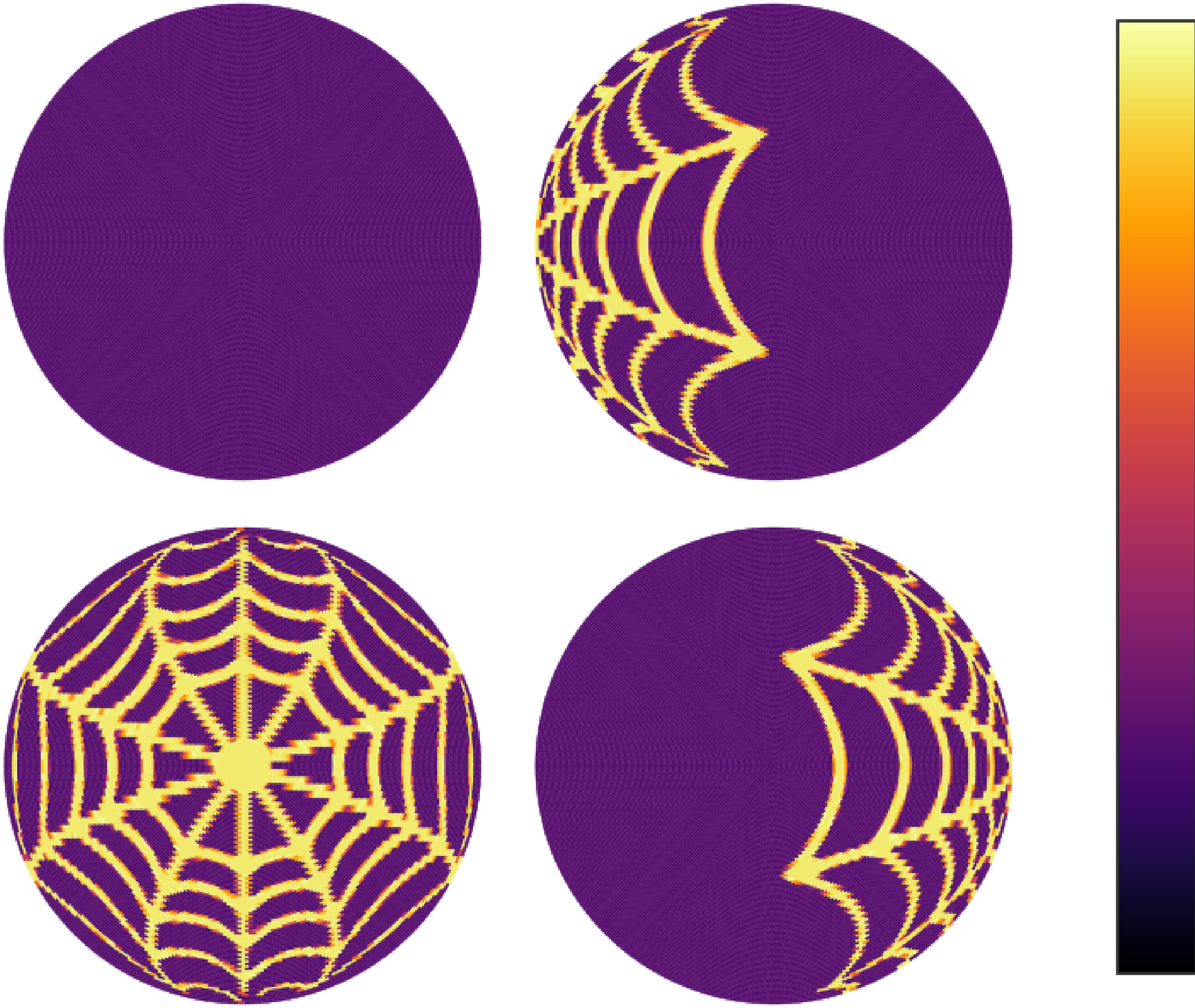
An example four phase plot:

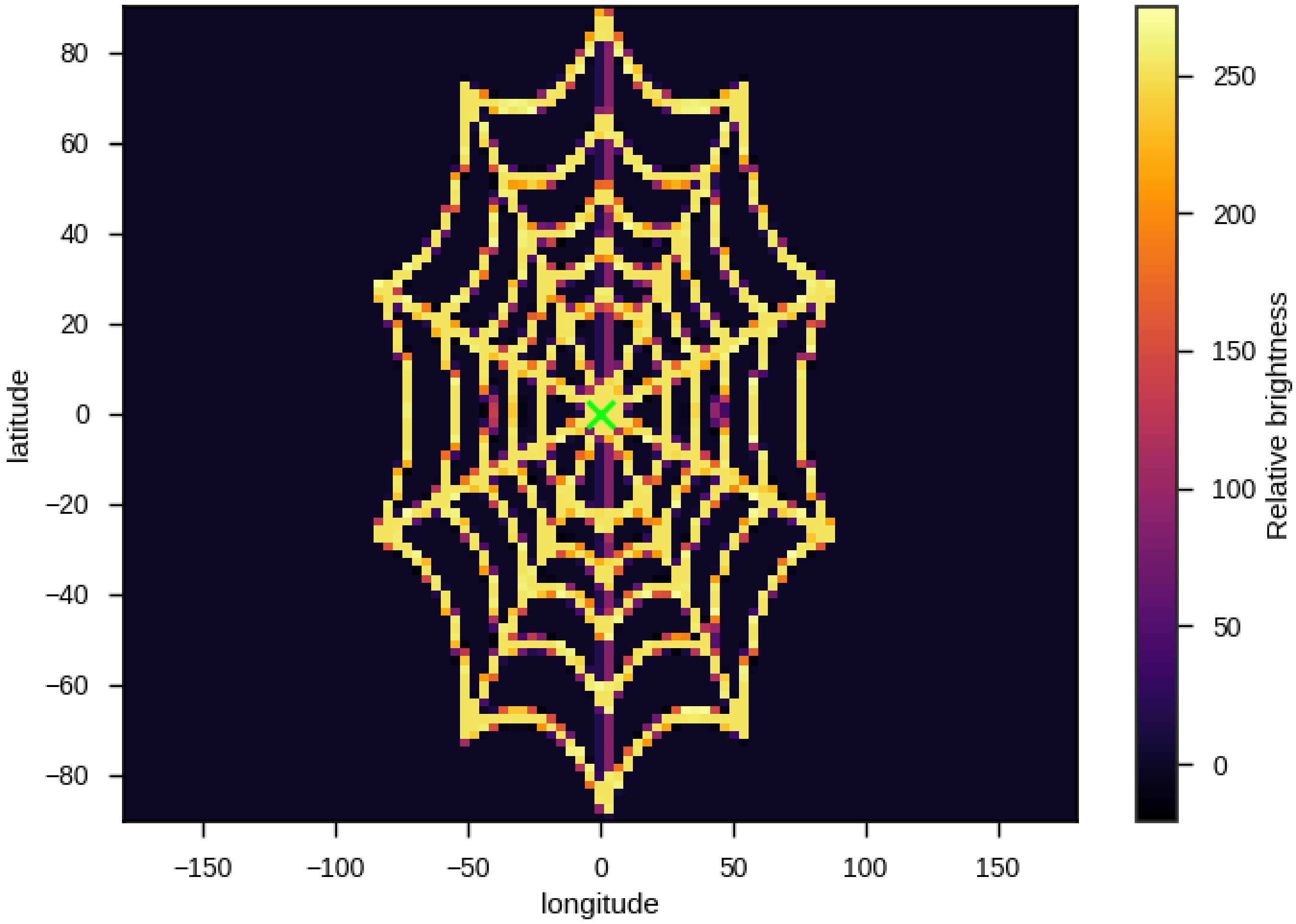
An example square plot:

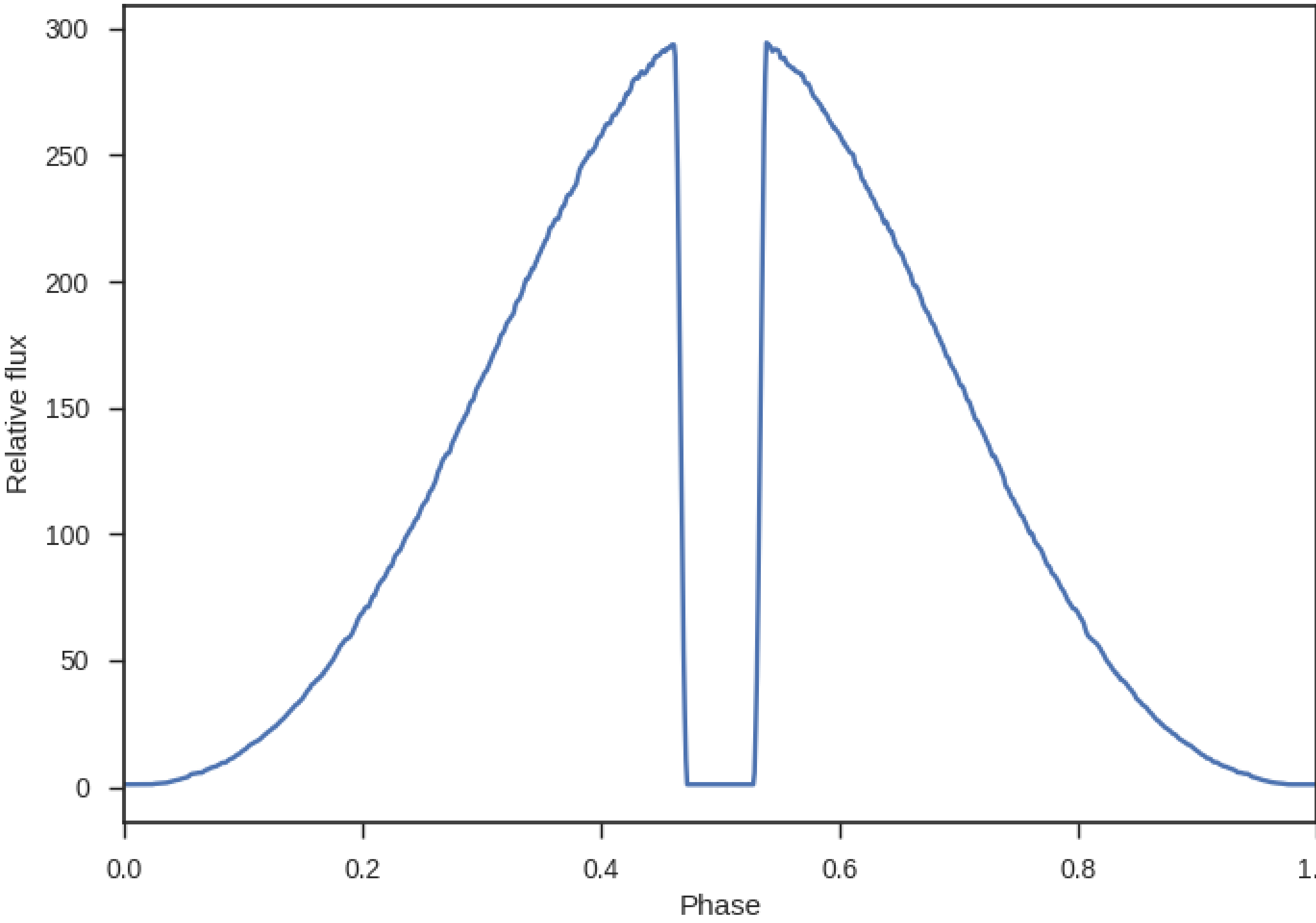
And the resulting phasecurveL




+1
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
Relative flux
0.0
0.2
0.4
0.6
0.8
1.
Phase
T night = 1000
T night = 600
T night = 1500




80
60
40
20
0
−20
−40
−60
−80
latitude
−150
−100
−50
0
50
100
150
longitude
250
200
150
100
50
0
Relative brightness


300
250
200
150
100
50
0
Relative flux
0.0
0.2
0.4
0.6
0.8
1.
Phase

CHAPTER 5

Stellar models

In some circumstances, you might want to attempt to directly determine the absolute brightness temperature of the planet, instead of just the brightness relative to the star. Some physical models may require you to do this, for example the Zhang and Showman (2017) model.

To do this you need the absolute brightness of the star - don't worry, spiderman has you covered! There are three options for stellar models that can be specified when the model parameters are initialized:

where options for the stellar model include "blackbody" (the default), "PHOENIX", and "path_to_model" (a user-specified spectrum).

5.1 Blackbody model

At the most basic level, you can assume that the spectrum of the star is simply blackbody with the effective temperature of the star. Users specify the effective temperature as a model parameter, and the bandpass of the observations must also be specified like so:

```
spider_params.T_s = 4520        # The stellar effective temperature in K
spider_params.l1 = 1.1e-6       # The starting wavelength in meters
spider_params.l2 = 1.7e-6       # The ending wavelength in meters
```

Blackbody stellar models are the default mode for spiderman. Over very wide bandpasses this will be good enough, but for narrower spectral ranges this could introduce significant errors, particularly for cooler stars with deep molecular absorption bands.

5.2 PHOENIX model

A more physically realistic option is to use model stellar spectra to determine the stellar flux - spiderman can do this as well, but it requires downloading an external library of spectra. The path to the library is specified using the .spidermanrc file, as follows:

Note: Currently, the only supported model spectra are the R=10000 PHOENIX models from this page: ftp://phoenix.astro.physik.uni-goettingen.de/MedResFITS/R10000FITS/PHOENIX-ACES-AGSS-COND-2011_R10000FITS_Z-0.0.zip

Download and unpack the model spectra, then make a ".spidermanrc" file in your home directory with a line that points to this model spectra with the keyword PHOENIX_DIR, like this:

PHOENIX_DIR : /path/to/PHOENIX/

As for the blackbody, users specify the wavelength limits for the bandpass and the effective temperature of the star.

```
spider_params = spiderman.ModelParams(brightness_model = 'zhang', stellar_model =
↪'PHOENIX')
spider_params.l1 = 1.1e-6        # The starting wavelength in meters
spider_params.l2 = 1.7e-6        # The ending wavelength in meters
spider_params.T_s = 4520         # The stellar effective temperature in K

.. warning:: spiderman currently only interpolates the stellar flux in 1D␣
↪(Temperature) and assumes by default that the star is a dwarf with logg 4.5 - 2d␣
↪interpolation with logg will be included in a future update
```

5.3 Custom stellar spectrum

It is also possible to use your own stellar spectrum. To do this, simply specify the path to the spectrum when you initialize the ModelParams class:

```
web_p = spiderman.ModelParams(brightness_model = 'zhang', stellar_model = 'path_to_
↪model')
```

where the spectrum is saved in a file called 'path_to_model'. This file must be formatted in two columns, where column (1) has the wavelength in meters and column (2) has the stellar flux in units of W/m^3/sr.

5.4 Precalculating grids of models

In order to speed up computation, spiderman can automatically generate a grid of the *summed stellar flux* in the defined bandpass as a function of stellar effective temperature, when calculating the flux of the star given its effective temperature spiderman will then use this grid to interpolate on to find the appropriate temperature, to a high level of precision.

If you a running an MCMC, or another numerical method that requires you to call spiderman many thousands of times, especially if you are including the stellar temperature as a model parameter, you should *precalculate* this grid before begining the model fit and pass it to spiderman to increase the efficiency. This can be done very easily with the stellar_grid module:

```
stellar_grid = spiderman.stellar_grid.gen_grid(l1,l2,logg=4.5, stellar_model =␣
↪stellar_model)
```

Where l1 and l2 are the begining and end of the spectral window in meters, logg is the cgs surface gravity of the star, and stellar_model is the model stellar spectrum ("blackbody", "PHOENIX", or "path_to_model"). The stellar_grid object is then passed to spiderman for every light curve generation instance, e.g.

```
lc = spider_params.lightcurve(t,stellar_grid=stellar_grid)
```

If a stellar grid is not provided, spiderman will calculate it internally every time lightcurve is called - this will be significantly less efficient for long runs.

CHAPTER 6

Instrument response

When calculating broadband phase curves, either for observations through a filter, or when summing all the data in a spectroscopic phase curve, the total instrument response may be required, as it weights how important each of the wavelengths are to the sum. Fortunately, spiderman has an easy way to account for this, simply provide a path to a "filter file"

```
spider_params.filter = 'myfilter.txt'
```

This filter file must be a plain text file that consists of two columns, the wavelength in metres and the corresponding instument response value (typically a number between 0 and 1) and must be in units of counts per photon. The code will then convolve the given filter function with the fluxes when calculating physical models with grids of blackbodies or stellar model spectra. Spiderman will linearly interpolate between the provided wavelength points.

If the filter function is too course, or if it contains a very sharply varying response then the results may not be accurate. In these cases it may be necessary to modify the "n_bb_seg" parameter in the lightcurve function, for which the default is 100.

Warning: SPIDERMAN normally calculates ratios in flux density assuming a uniform *energy flux* response - a uniform counts / photon response function will be different by a factor of hc / lambda, therefore it is possible to recover a different result with a uniform response function than you would get by setting the upper and lower bounds of the integration with l1 and l2.

CHAPTER 7

Acknowledgements

`spiderman` would not have happened without the following people:

- Laura Kreidberg was responsible for the early concept and much of the inspiration of this project.
- Xi Zhang for sharing his analytical solution to temperature distribution on a Hot Jupiter.
- The majority of this code was written during the Kavli Summer Program in Astrophysics 2016, my thanks to the organisers and participants for a stimulating work environment.

CHAPTER 8

Release Notes

CHAPTER 9

0.3.1 (2016/08/25)

- Updated API - more object oriented.
- Made fully compatible with BATMAN.
- Added intuitive plotting scripts.
- Made example ipython notebooks.

CHAPTER 10

0.2.2 (2016/08/10)

- First stable release.