pyLCSIM Documentation

Release 0.1

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DOCUMENTATION FOR PYLCSIM

1.1 Introduction

pyLCSIM is a python package to simulate X-ray lightcurves from coherent signals and power spectrum models.

Coherent signals can be specified as a sum of one or more sinusoids, each with its frequency, pulsed fraction and phase shift; or as a series of harmonics of a fundamental frequency (each with its pulsed fraction and phase shift).

Power spectra can be simulated from a model of the power spectrum density (PSD), using as a template one or more of the built-in library functions. The user can also define his/her custom models. Models are additive.

A PDF version of these notes is available here.

Warning: the current release (0.1) is HIGHLY EXPERIMENTAL! Use at your own risk...

1.2 Prerequisites

pyLCSIM requires Numpy (at least v1.8) and Astropy (at least v0.3).

Matplotlib is highly recommended if you want to plot your simulations.

1.3 Installation

The package can be downloaded here.

The installation follows the usual steps:

```
$ tar xzvf pyLCSIM-0.1.tar.gz
```

```
$ cd pyLCSIM-0.1
```

```
$ python setup.py install
```

The last step may require administrator privileges.

1.4 Example 1

Let's begin with a PSD model simulation.

We import the usual packages:

```
import matplotlib.pyplot as plt
import numpy as np
import pyLCSIM
```

We assume that our source has a rate of 30000 counts/s. Moreover, we have a 5000 counts/s background rate, and we have made a 50 s exposure. Our observation has a time resolution of 10 ms. We want to simulate a QPO at a frequency of 10 Hz, superimposed to a continuum modelled as a smoothly-varying broken power law (spectral indices 1 and 2, with a steepness change at 1 Hz). The required fractional RMS variation of the signal is 1%:

```
rate_src     = 30000.0
rate_bkg     = 5000.0
t_exp        = 50.0
dt           = 0.01
frms         = 0.01
```

The total bins of the lightcurve are therefore:

```
nbins = long(t_exp/dt)
```

The simulation follows as:

```
# Instantiate a simulation object
sim = pyLCSIM.Simulation()

# Add two PSD models: a smooth broken power law and a Lorentzian representing a QPO.
# See the documentation for details.
sim.addModel('smoothbknpo', [1., 1., 2., 1.])
sim.addModel('lorentzian', [10., 1., 100., 10])

# Run the simulation
sim.run(dt, nbins, rate_src, rms=frms)

# Add Poisson noise to the light curve
sim.poissonRandomize(dt, rate_bkg)

# Get lightcurve and power spectrum as 1-D arrays
time, rate = sim.getLightCurve()
f, psd = sim.getPowerSpectrum()
```

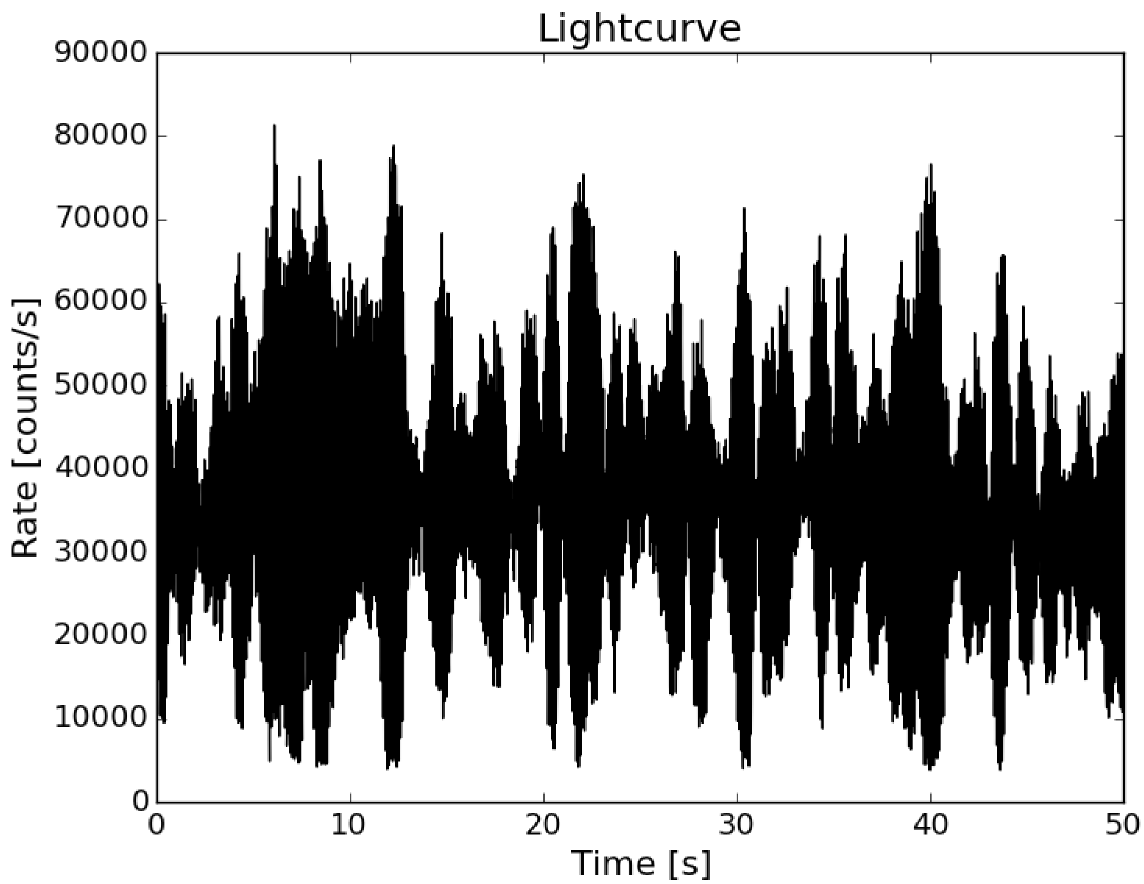
Done! We can save the results as FITS files:

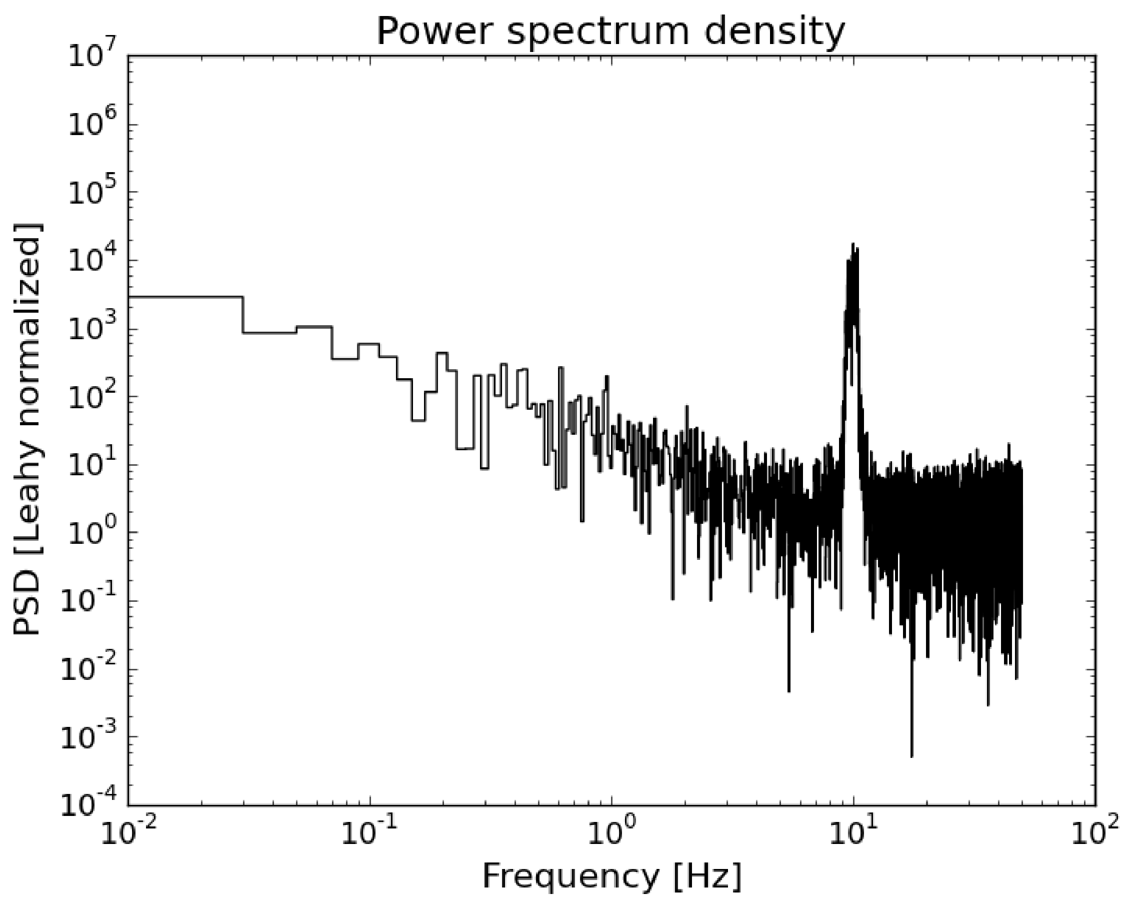
```
# Save FITS files with lightcurve and spectrum
pyLCSIM.saveFITSLC("myLC.fits", time, rate)
pyLCSIM.saveFITSPSD("myPSD.fits", f, psd)
```

and view the results:

```
# Plot the lightcurve and power spectrum
fig0 = plt.figure()
plt.plot(time, rate)
plt.xlabel("Time [s]")
plt.ylabel("Rate [counts/s]")
plt.title("Lightcurve")

fig1 = plt.figure()
plt.loglog(f, psd, drawstyle='steps-mid', color='black')
plt.xlabel("Frequency [Hz]")
plt.ylabel("PSD [Leahy normalized]")
plt.title("Power spectrum density")
```

```
plt.show()
```


Lightcurve
Rate [counts/s]
Time [s]
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
10
20
30
40
50



1.5 Example 2

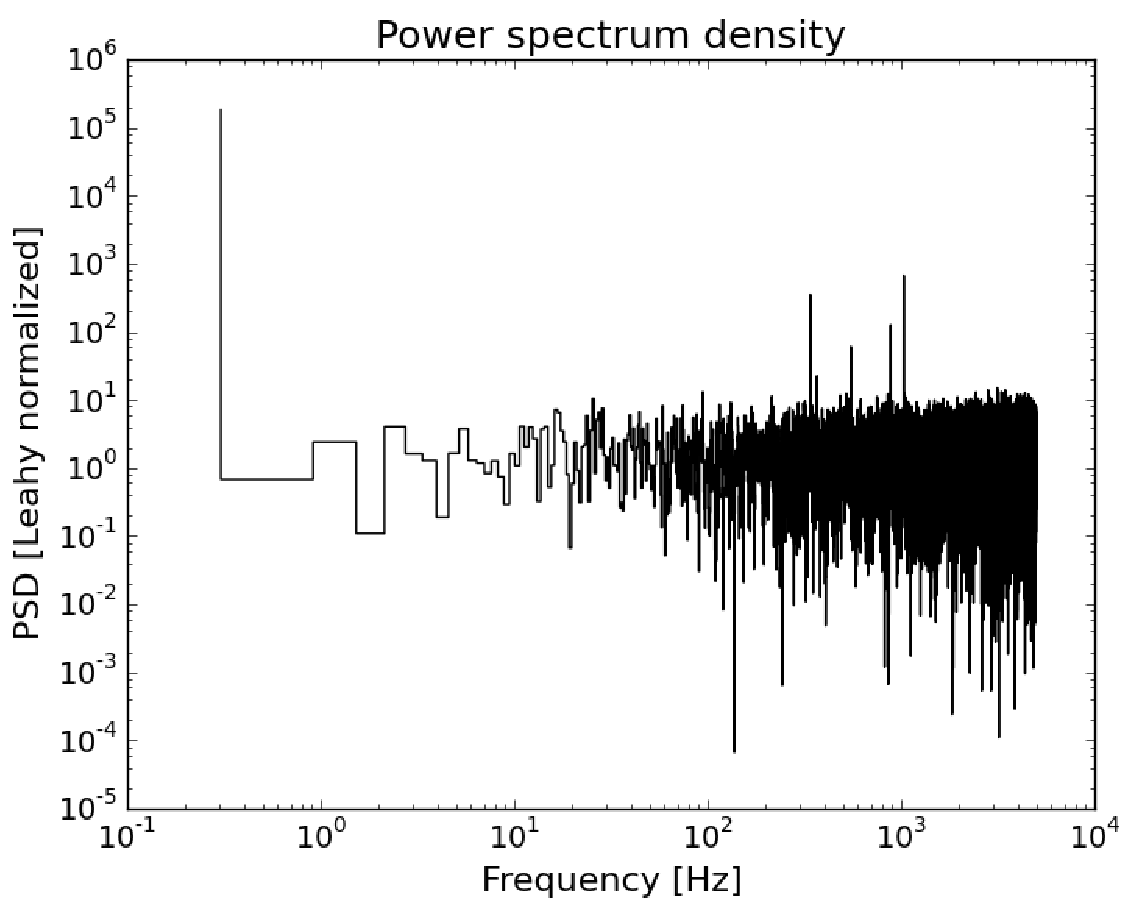
The following example shows the simulation of a coherent signal using a sum of sinusoids:

```
import matplotlib.pyplot as plt
import numpy as np
import pyLCSIM

rate_src     = 30000.0
rate_bkg     = 5000.0
t_exp        = 1.0
dt           = 0.0001
nbins = long(t_exp/dt)
```

Note the different exposure time (1 s) and time resolution (100 us):

```
# Instantiate a simulation object, this time as coherent
sim = pyLCSIM.Simulation(kind='coherent')

# Run the simulation, using:
# four sinusoidal frequencies: 340, 550, 883, 1032 Hz;
# with pulsed fractions 10%, 5%, 7% and 15% respectively;
# the third frequency has a 35 degree phase shift with respect to the others
sim.run(dt, nbins, rate_src, freq=[340, 550, 883, 1032], amp=[0.1, 0.05, 0.07, 0.15], phi=[0., 0, 35
```

```
# Add Poisson noise to the light curve
sim.poissonRandomize(dt, rate_bkg)

# Get lightcurve and power spectrum as 1-D arrays
time, rate = sim.getLightCurve()
f, psd = sim.getPowerSpectrum()

# Plot the lightcurve and power spectrum
fig0 = plt.figure()
plt.plot(time, rate)
plt.xlabel("Time [s]")
plt.ylabel("Rate [counts/s]")
plt.title("Lightcurve")

fig1 = plt.figure()
plt.loglog(f, psd, drawstyle='steps-mid', color='black')
plt.xlabel("Frequency [Hz]")
plt.ylabel("PSD [Leahy normalized]")
plt.title("Power spectrum density")

# Save FITS files with lightcurve and spectrum
pyLCSIM.saveFITSLC("myLC.fits", time, rate)
pyLCSIM.saveFITSPSD("myPSD.fits", f, psd)

plt.show()
```



1.6 Example 2

Finally, an example with a fundamental frequency and two harmonics:

```
import matplotlib.pyplot as plt
import numpy as np
import pyLCSIM

rate_src    = 300000.0
rate_bkg    = 3000.0
t_exp       = 1.0
dt          = 0.0001
phase_shift = 0.
nbins = long(t_exp/dt)

print nbins

# Instantiate a simulation object, this time as coherent
sim = pyLCSIM.Simulation(kind='coherent')


# Run the simulation:
# Fundamental at 500 Hz, 3 harmonics (500, 1000, 1500 Hz)
# with pulsed fractions 10%, 5% and 15% respectively
sim.run(dt, nbins, rate_src, freq=500, nha=3, amp=[0.1, 0.05, 0.15])

# Add Poisson noise to the light curve
sim.poissonRandomize(dt, rate_bkg)

# Get lightcurve and power spectrum as 1-D arrays
time, rate = sim.getLightCurve()
f, psd = sim.getPowerSpectrum()

# Plot the lightcurve and power spectrum
fig0 = plt.figure()
plt.plot(time, rate)

fig1 = plt.figure()
plt.loglog(f, psd, drawstyle='steps-mid', color='black')

# Save FITS files with lightcurve and spectrum
pyLCSIM.saveFITSLC("myLC.fits", time, rate)
pyLCSIM.saveFITSPSD("myPSD.fits", f, psd)

plt.show()
```

1.7 Main module

A python package to simulate X-ray lightcurves from coherent signals and power spectrum models.

class `pyLCSIM.`**`Simulation`**(*kind='psd'*)

Main simulation class.

History: v0.1: Riccardo Campana, 2014. Initial python implementation.

`addModel`(*modelName*, *modelParams*)

Append simulation model to model dictionary

getLightCurve()
Get lightcurve as time and rate arrays

getPowerSpectrum()
Get power spectrum as frequency and power arrays

info()
Prints simulation informations

run(*dt*, *nbins_old*, *mean*, *rms=None*, *freq=None*, *nha=None*, *amp=None*, *phi=None*, *verbose=False*)
Run the simulation

pyLCSIM.**lcsinusoid**(*dt=1.0*, *nbins=65536*, *mean=0.0*, *freq=None*, *nha=1*, *amp=None*, *phi=None*)
Generate coherent signals as a sequence of sinusoids (if len(freq) > 1) or of the fundamental frequency plus nha-1 harmonics (if len(freq) == 1), each with normalized pulsed fraction amp[i].

Kwargs: dt: time resolution of the lightcurve to be simulated (default: 1.0).

nbins: Number of bins of the simulated lightcurve (default: 65536).

freq: if float: frequency of the fundamental harmonic, if array: frequencies of sinusoids.

nha: number of harmonics (>1)

amp: array with nha/nfreq elements; pulsed fraction for each frequency

phi: array with nha/nfreq elements; phases (in degrees!) for each frequency

Returns: time: time array

rate: array of count rates

History:

v0.1: Riccardo Campana, 2014. Initial python implementation, from the IDL procedure
lcharmonics.pro v0.0.3 by I. Donnarumma & R. Campana

pyLCSIM.**lcpsd**(*dt=1.0*, *nbins=65536*, *mean=0.0*, *rms=1.0*, *seed=None*, *models=None*, *phase_shift=None*)
Simulate a light-curve with a general power spectrum shape. For the underlying algorithm see: J. Timmer & M. Koenig, "On generating power law noise", A&A, 300, 707-710 (1995).

Kwargs: dt: time resolution of the lightcurve to be simulated

nbins: Number of bins of the simulated lightcurve (default:65536). Should be power of two for optimum performance (FFT...)

mean: Mean count rate of the simulated lightcurve (default: 0.).

rms: Total fractional RMS of the simulated lightcurve.

seed: Seed for the random number generator.

models: List of tuples, each containing: a. Name of a function returning the desired PSD shape, b. Parameters of the model (argument to model). Total model is the sum of these tuples.

phase_shift: Constant phase shift (in degrees) to the FFT.

Returns: time: time array.

rate: array of count rates.

History: v0.1: Riccardo Campana, 2014. Initial python implementation. Based on AITLIB IDL procedure timmerlc.pro

pyLCSIM.**poisson_randomization**(*rate*, *dt=1.0*, *bkg=0.0*, *seed=None*)
Poisson randomization of the rate array.

Args: rate: input array of count rates (in cts/s).

Kwargs: dt: time resolution of the lightcurve to be simulated.

bkg: Mean count rate of the simulated lightcurve (default: 0.0).

seed: Seed for the random number generator.

Returns: newrate: Array of Poisson randomized count rates of length n.

History: v0.1: Riccardo Campana, 2014. Initial python implementation.

`pyLCSIM.`**`psd`**(*time*, *rate*, *norm='leahy'*)

Returns power spectral density from a (real) time series with Leahy normalization.

Args: time: array of times (evenly binned).

rate: array of rate in counts/s.

Kwargs: norm: Normalization (only Leahy for now).

Returns: f: array of frequencies.

p: power spectrum.

History: v0.1: Riccardo Campana, 2014. Initial python implementation.

`pyLCSIM.`**`rebin`**(*x*, *y*, *nbins*, *mode='rate'*)

Linearly rebins the (x, y) 1-D arrays using #nbins new bins, taking for each new element the mean of the corresponding x elements, and the sum (if mode=='counts') or the mean (if mode=='rate') of the corresponding y elements.

Args: x: x array (same length as y)

y: y array (same length as x)

nbins: Number of new bins. Should be a factor of len(x) == len(y).

Kwargs: mode: 'counts' or 'rate'; returns sum or mean of y-array elements

Returns: xreb: rebinned x array

yreb: rebinned y array

History: v0.1: Riccardo Campana, 2014. Initial python implementation.

`pyLCSIM.`**`logrebin`**(*x*, *y*, *nbins*, *mode='rate'*)

Logarithmically rebins the (x, y) 1-D arrays using #nbins new bins, taking for each new element the logarithmic mean of the corresponding x elements, and the sum (if mode=='counts') or the mean (if mode=='rate') of the corresponding y elements.

Args: x: x array (same length as y)

y: y array (same length as x)

nbins: Number of new bins.

Kwargs: mode: 'counts' or 'rate'; returns sum or mean of y-array elements

Returns: xreb: rebinned x array

yreb: rebinned y array

History: v0.1: Riccardo Campana, 2014. Initial python implementation.

`pyLCSIM.`**`saveFITSLC`**(*outfilename*, *time*, *rate*, *clobber=True*)

Produce an output FITS file containing a lightcurve.

Args: outfilename: Name of the output FITS file

time: Array of times

rate: Array of count rates

Kwargs: clobber: if True, overwrites existing files with same name

Returns: none

History: v0.1: Riccardo Campana, 2014 Initial python implementation.

`pyLCSIM.`**`saveFITSPSD`**(*outfilename*, *freq*, *psd*, *clobber=True*)

Produce an output FITS file containing a power spectrum.

Args: outfilename: Name of the output FITS file

freq: Array of frequencies

psd: Array of power spectrum

Kwargs: clobber: if True, overwrites existing files with same name

Returns: none

History: v0.1: Riccardo Campana, 2014 Initial python implementation.

1.8 Submodule: psd_models

Contains the analytic models for the power spectrum density.

`pyLCSIM.psd_models.`**`lorentzian`**(*x*, *p*)

Generalized Lorentzian function.

(**WARNING**: for n != 2 the function is no more normalized!)

Args: x: (non-zero) frequencies.

p[0]: x0 = peak central frequency.

p[1]: gamma = FWHM of the peak.

p[2]: value of the peak at x = x0.

p[3]: n = power coefficient.

The quality factor is given by Q = x0/gamma.

Returns: f: psd model.

History: v0.1: Riccardo Campana, 2014. Initial python implementation.

`pyLCSIM.psd_models.`**`smoothbknpo`**(*x*, *p*)

Smooth broken power law.

Args: x: (non-zero) frequencies.

p[0]: Normalization.

p[1]: power law index for f–> 0.

p[2]: power law index for f–> oo.

p[3]: break frequency.

Returns: f: psd model.

History: v0.1: Riccardo Campana, 2014. Initial python implementation.

CHAPTER

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