Fruitbat Documentation

Release 0.0.1

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Mar 06, 2019

User Guide

This is the documentation for the **fruitbat** package, an easy and convenient way to estimate the redshift of Fast Radio Bursts. **Fruitbat** was created by *Adam Batten*

CHAPTER 1

Introduction

1.1 What are FRBs?

Fast Radio Bursts (FRBs) are a class of radio frequency transients that currently have an unknown astrophysical origin[1]. FRB are characterised by their large dispersion measures (DMs; $100 - 2500\ \mathrm{pc\ cm^{-3}}$) and short durations ($30\ \mu\mathrm{s} - 30\ \mathrm{ms}$).

For a database of all currently known FRBs see frbcat.org

[1] At the time of writing (Feburary 2019) an optical counterpart of FRBs has not been detected.

CHAPTER 2

Getting started

2.1 Installation

You can install the latest release of `fruitbat` from PyPi by running the following:

```
pip install fruitbat
```

You can install the latest deveopment version of `fruitbat` by cloning the repository:

```
git clone https://github.com/abatten/fruitbat
cd fruitbat
pip install .
```

2.1.1 Requirements

- Numpy >= 1.12.0
- Astropy >= 2.0.0
- Scipy >= 1.0.0
- Pyymw16 >= 2.0.4

Pyymw16 is a python wrapper for the YMW16 galactic dispersion measure model.

2.2 Using Fruitbat

A detailed explanation of this example can be viewed at Using Fruitbat.

2.2.1 Example Calculation

```
import fruitbat

# Create a Frb Object with DM and Galactic Coordinates
FRB180110 = fruitbat.Frb("FRB180110", dm=715.7, gl="7.8", gb="-51.9")

# Calculate the DM contribution from the Milky Way
FRB180110.calc_dm_galaxy(model="ymw16")

# Calculate the Redshift of the FRB using the relation from Zhang (2018)
FRB180110.calc_redshift(method="zhang2018", cosmology="planck2018")
```

CHAPTER 3

Using Fruitbat

Example

CHAPTER 4

Methods and Cosmology

When calculation the redshift of an FRB there are varius methods that you can choose from.

4.1 Methods

There are various methods

4.2 Cosmology

Each method in **fruitbat** has a list of pre-calculated lookup tables with different cosmologies. The table below lists the parameters that are used for each cosmology.

Cosmological Parameters				
Keyword	H_0	Ω_b	Ω_m	Ω_Λ
`'wmap2013'`	69.32	0.04628	0.2865	0.7135
`'planck2013'`	67.80	0.04816	0.3063	0.6920
`'planck2015'`	67.74	0.04860	0.3089	0.6911
`'planck2018'`	67.66	0.04897	0.3111	0.6889
`'eagle'`	67.77	0.04825	0.307	0.693

CHAPTER 5

Guidelines

5.1 Reference

If you use FRBz please cite our paper. . . .

5.2 License

```
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```

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```

CHAPTER 6

fruitbat.Frb

class fruitbat.**Frb**(*dm*, ***, *name=None*, *raj=None*, *decj=None*, *gl=None*, *gb=None*, *dm_galaxy=0.0*, *dm_excess=None*, *z_host=None*, *dm_host_est=0.0*, *dm_host_loc=0.0*, *dm_index=None*, *scatt_index=None*, *snr=None*, *w_obs=None*, *s_peak_obs=None*, *f_obs=None*, *utc=None*, *dm_uncert=0.0*, *z_uncert=0.0*)

Create a *Frb* object using the observered properties of a FRB to properties including

To define a *Frb* object all it requires is an observed dispersion measure.

Parameters **dm** (*float*) – The observed dispersion measure of the FRB. This is without Milky Way or host galaxy subtraction. Units: $\mathrm{pc\ cm^{-3}}$

Keyword Arguments

- **name** (*str or None, optional*) – The name of the frb object. Default: *None*
- **raj** (*str or None, optional*) – The right ascension in J2000 coordinates of the best estimate of the FRB position. Default: *None*
- **decj** (*str or None, optional*) – The declination in J2000 coordinates of the best estimate of the FRB position. Default: *None*
- **gl** (*str or None, optional*) – The Galactic longitude in degrees of the best estimate of the FRB position. Default: *None*
- **gb** (*str or None, optional*) – The Galactic latitude in degrees of the best estimate of the FRB position. Default: *None*

Other Parameters

- **dm_galaxy** (*float, optional*) – The modelled contribution to the FRB DM by electrons in the Milky Way. Units: $\mathrm{pc\ cm^{-3}}$ Default: 0.0
- **dm_excess** (*float or None, optional*) – The DM excess of the FRB over the estimated Galactic DM. If *dm_excess* is *None*, then *dm_excess* is calculated automatically with *calc_dm_excess()*. Units: $\mathrm{pc\ cm^{-3}}$ Default: *None*
- **z_host** (*float or None, optional*) – The observed redshift of the localised FRB host galaxy. Default: *None*

- **dm_host_est** (*float, optional*) – The estimated contribution to the measured FRB DM from originating from the FRB's host galaxy. This value is the amount of DM the host galaxy contributes to the observed DM, *not* the DM of the host galaxy. Units: $\mathrm{pc\ cm^{-3}}$ Default: 0.0
- **dm_host_loc** (*float, optional*) – The dispersion measure of a localised FRB host galaxy. This value is *not* the contribution to the observed DM, but the DM at the host galaxy. The observed DM is `dm_host_loc` but attenuated by a factor of (1 + z). Units: $\mathrm{pc\ cm^{-3}}$ Default: 0.0
- **dm_index** (*float or None, optional*) – The dispersion measure index of the burst α such that $\mathrm{DM} \propto \nu^{-\alpha}$ Default: *None*
- **scatt_index** (*float or None, optional*) – The scattering index (β) of the FRB pulse. The scattering index describes how the width (W) of the FRB pulse evolves with frequency ν such that $\mathrm{W} \propto \nu^{-\beta}$. Default: *None*
- **snr** (*float or None, optional*) – The signal-to-noise of the burst. Default: *None*
- **w_obs** (*float or None, optional*) – The observed width of the pulse obtained by a pulse fitting algorithm. Units: ms Default: *None*
- **s_peak_obs** (*float or None, optional*) – The observed peak flux density of the burst. Units: Jy Default: *None*
- **f_obs** (*float or None, optional*) – The observed fluence of the FRB. If `f_obs` is *None* and both `w_obs` and `s_peak_obs` are not *None* then `f_obs` is automatically calculated by `w_obs` x `s_peak_obs` Units: $\mathrm{Jy\ ms}$ Default: *None*
- **utc** (*str or None, optional*) – The UTC time of the FRB Burst. Default: *None*
- **dm_uncert** (*float, optional*) – The uncertainty in the dispersion measure. Units: $\mathrm{pc\ cm^{-3}}$ Default: 0.0
- **z_uncert** (*float, optional*) – The uncertainty in the redshift of the FRB. Default: 0.0

Example

```
>>> import fruitbat
>>> FRB = fruitbat.Frb(879, gl="12:31:40.5", gb="3:41:10.0")
>>> FRB.calc_dm_galaxy()
>>> FRB.calc_redshift()
```

calc_dm_excess()

Calculates the dispersion measure excess of the FRB by subtracting the DM contribution from the Milky Way.

Returns **dm_excess** – The dispersion measure excess.

Return type float

Notes

$\mathrm{DM_{excess}}$ is calculated as follows:

$$DM_{excess} = DM - DM_{galaxy}$$

---

calc_dm_galaxy(*model='ymw16'*)

Calculates the dispersion measure contribution of the Milky Way from either (`raj`, `decj`) or (`gl`, `gb`).

Parameters **model** (*str, optional*) – The Milky Way dispersion measure model. Default: ymw16

calc_dm_igm()

Calculates the dispersion measure of the intergalactic medium along the line-of-sight of the FRB. This can only be done if the redshift and dispersion measure contribution of the FRB host galaxy is known.

Returns **dm_igm** – The dispersion measure contribution of the IGM.

Return type float

Notes

DM_{IGM} is calculated as follows:

$$DM_{IGM} = DM_{excess} - \frac{DM_{host,loc}}{1+z}$$

---

calc_f_obs()

Calculates the observed fluence of the FRB. This requires *w_obs* and *s_peak_obs* to not be *None*.

Returns The fluence of the FRB.

Return type float

Notes

$\mathrm{F_{obs}}$ is calculated as follows:

$$\mathrm{F_{obs}} = \mathrm{W_{obs}} \times \mathrm{S_{peak,obs}}$$

---

calc_redshift(*method='inoue2004'*, *cosmology='Planck18'*, *subtract_host=False*)

Calculate the redshift of the FRB from its *dm*, *dm_excess* or *dm_excess* - *dm_host_est*.

Parameters

- **method** (*str, optional*) – The approximation to use when calculating the redshift. Avaliable methods: ioka2003, inoue2004, zhang2018
- **cosmology** (*str, optional*) – The method *inoue2004* has the option to choose which cosmology to assume when performing the redshift estimation. Avaliable cosmologies: WMAP5, WMAP7, WMAP9, Planck13, Planck15, Planck18
- **subtract_host** (*bool, optional*) – Subtract *dm_host_est* from the *dm_excess* before calculating the redshift. This is is used to account for the dispersion measure that arises from the FRB host galaxy.

Returns The redshift of the FRB.

Return type float

Notes

The methods section in the documentation has a discription of each methods and where they should apply.

The cosmology section of the documentation has a list of the cosmological parameters used in each cosmology method.

---

calc_skycoords()
Calculates the skycoord position on the sky of the FRB from (*raj*, *decj*) or (*gl*, *gb*).

Returns The sky coordinates of the FRB.

Return type astropy.coordinates.sky_coordinate.SkyCoord

decj
astropy.coordinates.angles.Latitude or None – The declination in J2000 coordinates of the best estimate of the FRB position.

dm
float – The observed dispersion measure of the FRB.

dm_excess
float – The dispersion measure with the Milky Way component subtracted.

dm_galaxy
float – The Milky Way component of the dispersion measure.

dm_host_est
float – The dispersion measure from the FRB host galaxy

dm_host_loc
float – The dispersion measure from a localised FRB host galaxy

dm_igm

f_obs
The Milky Way component of the dispersion measure.

gb
astropy.coordinates.angles.Latitude or None – The latitude in galactic coordinates of the best estimate of the FRB position.

gl
astropy.coordinates.angles.Longitude or None – The longitude in galactic coordinates of the best estimate of the FRB position.

name
str – The name of the FRB object.

raj
astropy.coordinates.angles.Longitude or None – The right accension in J2000 coordinates of the best estimate of the FRB position.

s_peak_obs
**float or None* – The observed peak flux density of the burst. Units*

skycoords
astropy.coordinates.sky_coordinate.SkyCoord or None – The skycoords of the FRB. This is calculated from either (*raj*, *decj*) or (*gl*, *gb*).

w_obs
float or None – The observed width of the pulse obtained by a pulse fitting algorithm. Units: ms

z
float or None – The estimated redshift of the burst. By default this assumes that the entire *dm_excess* arrives from the IGM and the host galaxy of the FRB and any surrounding material contribute nothing to the total DM. This should be taken as an upper limit to the bursts true redshift. To provide an estimate of the DM contribution due to he host galaxy, set *dm_host_est* to a non-zero value and use `subract_host=True` when using *calc_redshift()*.

z_host
float or None – The redshift of the localised FRB host galaxy. Note that this an observed quantity, not the estimated redshift `z` calculated with `calc_redshift()`

CHAPTER 7

fruitbat.estimate

fruitbat.estimate.**redshift**(*dm*, *dm_uncert=0.0*, *method='inoue2004'*, *cosmology='Planck18'*)

Returns the redshift of a given dispersion measure using a specified DM-z relation.

Parameters

- **dm** (*float*) – Dispersion Measure. Units: $\mathrm{pc\ cm^{-3}}$
- **dm_uncert** (*float or None*) – The uncertainty in the dispersion measure. Units: $\mathrm{pc\ cm^{-3}}$
- **method** (*string, optional*) – The DM-z relation to use to calculate the redshift. Avaliable methods are: ioka2003, inoue2004, zhang2018. Default: *'inoue2004'*
- **cosmology** (*string, optional*) – Avaliable cosmologies: WMAP5, WMAP7, WMAP9, Planck13, Planck15, Planck18. Default: *'planck2018'*

Returns

- **z** (*float*) – Redshift
- **z_err** (*float*) – The uncertianty in the redshift estimation. If *dm_uncert* is *None* then *z_err* = 0.

Notes

Cosmology has a list of the cosmological parameters used in each cosmology method.

fruitbat.estimate.**methods**(*string=False*)

Defines the list of avaliable method keywords.

Methods currently avaliable: ioka2003, inoue2004, zhang2018

Parameters **string** (*bool, optional*) – If True, return a string of keywords instead of a list.

Returns A list containing the valid method keywords. If `string=True` it returns a single string listing all the keywords.

Return type list or str

CHAPTER 8

fruitbat.utils

Utility functions for Fruitbat

fruitbat.utils.**create_lookup_table**(*filename*, *method*, *cosmology*, *zmin=0*, *zmax=30*, *num_samples=100000.0*)

Creates a lookup table

Parameters

- **filename** (*str*) –
- **method** (*str*) –
- **cosmology** (*dict*) – A dictionary containing the cosmology parameters for the Hubble constant, Matter density, Baryon density and Dark Energy density. *cosmology* must contain values for the following keys: `'H0'`, `'Omega_m'`, `'Omega_b'`, `'Omega_L'`
- **zmin** (*int or float, optional*) – The minimum redshift in the table. Default: 0
- **zmax** (*int or float, optional*) – The maximum redshift in the table. Default: 30
- **num_samples** (*int, optional*) – The number of dispersion measure samples to perform before interpolation. Default: 100000

Returns

Return type None

fruitbat.utils.**load_lookup_table**(*filename*, *data_dir='data'*)

Opens a saved *.npy* file containing an interpolated 1D function.

Parameters

- **filename** (*str*) – The name of the file to load.
- **data_dir** (*str, optional*) – The directory containing the data. The whole path must be specified except if `data_dir` == 'data' then it will search in the *data* subdirectory of the source code. Default: 'data'

Returns Function

Return type scipy.interpolate.interpolate.interp1d

CHAPTER 9

fruitbat.cosmology

Module for defining different cosmologies

fruitbat.cosmology.**WMAP5**()
WMAP5 instance of FlatLambdaCDM cosmology

(from Komatsu et al. 2009, ApJS, 180, 330, doi: 10.1088/0067-0049/180/2/330. Table 1 (WMAP + BAO + SN ML).)

fruitbat.cosmology.**WMAP7**()
WMAP7 instance of FlatLambdaCDM cosmology

(from Komatsu et al. 2011, ApJS, 192, 18, doi: 10.1088/0067-0049/192/2/18. Table 1 (WMAP + BAO + H0 ML).)

fruitbat.cosmology.**WMAP9**()
WMAP9 instance of FlatLambdaCDM cosmology

(from Hinshaw et al. 2013, ApJS, 208, 19, doi: 10.1088/0067-0049/208/2/19. Table 4 (WMAP9 + eCMB + BAO + H0, last column))

fruitbat.cosmology.**Planck13**()
Planck13 instance of FlatLambdaCDM cosmology

(from Planck Collaboration 2014, A&A, 571, A16 (Paper XVI), Table 5 (Planck + WP + highL + BAO))

fruitbat.cosmology.**Planck15**()
Planck15 instance of FlatLambdaCDM cosmology

(from Planck Collaboration 2016, A&A, 594, A13 (Paper XIII), Table 4 (TT, TE, EE + lowP + lensing + ext))

fruitbat.cosmology.**Planck18**()
Planck18 instance of FlatLambdaCDM cosmology

(from Planck 2018 results. VI. Cosmological Parameters, A&A, submitted, Table 2 (TT, TE, EE + lowE + lensing + BAO))

fruitbat.cosmology.**create_cosmology**(*parameters=None*, *name=None*)
A wrapper to create custom astropy cosmologies.

The only avaliable cosmology types in this method are: FlatLambdaCDM, FlatwCDM, LambdaCDM and wCDM. See astropy.cosmology for more details on these types of cosmologies. To create a cosmology of a type that isn't listed above, it will have to be created directly using astropy.cosmology.

Parameters

- **parameters** (*dict or None*) – A dictionary containing the cosmological parameters. The names of the parameters must conform to the same format as the parameters used in astropy.cosmology. If *parameters* is *None* then default values for each parameter is used.
- **name** (*str or None, optional*) –
- **name of the cosmology. Default** (*The*) –

Returns

Return type cosmology

Notes

Default parameter values:

```
params = {'H0': 70, 'Om0': 0.3, 'Oc0': 0.26, 'Ob0': 0.04, 'Neff': 3.04,
          'flat': True, 'Tcmb0': 0.0, 'm_nu': 0.0, 'w0': -1}
```

If `'flat'` is set to `False` then a value of `'Ode0'` (current dark energy density) should be specified.

---

fruitbat.cosmology.**builtin**()

Create a dictionary of the builtin cosmologies with keywords and functions.

Returns A dictionary containing the keywords and function for each cosmology.

Return type dict

fruitbat.cosmology.**keys**()

Returns a string constaining all the keywords for builtin cosmologies.

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