

# RAiSERed: radio continuum redshifts for lobed AGNs

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## RAISERED DOCUMENTATION

This document describes the functions in the *RAiSERed* code and provides examples of accepted usage to calculate radio continuum redshifts and to calibrate the model using objects with known spectroscopic redshifts. The code is written in *python* and imports standard packages including *numpy*, *scipy* and *matplotlib*, and the specialised package *noisyopt*.

### RAiSERed\_list

**RAiSERed.RAiSERed\_list()**

Create an empty list of radio AGNs each stored in a RAiSERed\_obj.

**Returns:**      **raisered\_list** : *RAiSERed\_list*

Empty list of radio AGNs each stored in a RAiSERed\_obj. The list is of type RAiSERed\_list which inherits basic functions from python lists and provides additional functionality.

### RAiSERed\_add

**RAiSERed.RAiSERed\_add(raisered\_list, source, freq, flux, size, axis, inj, brkfreq, specz=None, calib=True, series=None, nredshifts=50, nsimulations=10000)**

Add the name, observed attributes, and optional fit parameters for a radio AGN to the list of sources.

**Parameters:**    **raisered\_list** : *RAiSERed\_list*

List of radio AGNs each stored in a RAiSERed\_obj.

**source** : *str*

Specify name of radio AGN. The suffixes ‘N’, ‘S’, ‘E’ and ‘W’ are used to designate the two lobes of a given source.

**freq** : *float or list*

Specify frequency of radio flux density as: mean; or mean and standard deviation; or mean, standard deviation and skewness. Expected units are Hertz; values given in Megahertz and Gigahertz are converted in most instances.

**flux** : *float or list*

Specify radio flux density of lobe as: mean; or mean and standard deviation; or mean, standard deviation and skewness. Expected units are Janskys.

**size** : *float or list*

Specify angular size of lobe as: mean; or mean and standard deviation; or mean, standard deviation and skewness. Expected units are arcseconds.

**axis** : *float or list*

Specify axis ratio of lobe as: mean; or mean and standard deviation; or mean, standard deviation and skewness.

**inj** : *float or list*

Specify electron energy distribution injection index as: mean; or mean and standard deviation; or mean, standard deviation and skewness.

**brkfreq** : *float or list*

Specify break frequency as: mean; or mean and standard deviation; or mean, standard deviation and skewness. Expected units are log-space Hertz.

**specz** : *float, optional*

Specify spectroscopic redshift of calibrator sources if known. The default value is None.

**calib** : *bool, optional*

Specify if source can be used as a calibrator; only sources with spectroscopic redshifts can be used as calibrators irrespective of this value. The default value is True.

**series** : *int, optional*

Group sources with integer categories for use when plotting. The default value is None.

**nredshifts** : *int, optional*

Specify number of log-space redshift bins from  $z = 0$  to 10 to include in initial search for peak of redshift probability density function. The default value is 50.

**nsimulations** : *int, optional*

Specify target number of simulations in initial search for peak of redshift probability density function; the actual number used will vary to optimise computational efficiency. The default value is 10000.

**Returns:** **raisedred\_obj** : *RAiSERed\_obj, optional*

Return object storing entered radio AGN data if invalid list passed in as input. The object will be appended to a valid list and no variable will be returned.

## RAiSERed

RAiSERed.RAiSERed(raisedred\_list, b1=None, b2=None, b3=None, b4=None)

Calculation and calibration of radio continuum redshifts for radio AGNs stored in list. The calibration is only performed if five or more calibrators are included in the list.

**Parameters:** **raisedred\_list** : *RAiSERed\_list*

List of radio AGNs each stored in a RAiSERed\_obj.

**b1** : *float, optional*

Specify calibration constant  $b_1$ . This parameter is only used if  $b_2$ ,  $b_3$  and  $b_4$  are also specified. The default value is  $b_1 = 0$ .

**b2** : *float, optional*

Specify calibration constant  $b_2$ . This parameter is only used if  $b_1$ ,  $b_3$  and  $b_4$  are also specified. The default value is  $b_2 = 0$ .

**b3** : *float, optional*

Specify calibration constant  $b_3$ . This parameter is only used if  $b_1$ ,  $b_2$  and  $b_4$  are also specified. The default value is  $b_3 = 0$ .

**b4** : *float, optional*

Specify calibration constant  $b_4$ . This parameter is only used if  $b_1$ ,  $b_2$  and  $b_3$  are also specified. The default value is  $b_4 = 0$ .

**Returns:** **b1** : *float, optional*

Return calibration constant  $b_1$  if five or more calibrators included in the list.

**b2** : *float, optional*

Return calibration constant  $b_2$  if five or more calibrators included in the list.

**b3** : *float, optional*

Return calibration constant  $b_3$  if five or more calibrators included in the list.

**b4** : *float, optional*

Return calibration constant  $b_4$  if five or more calibrators included in the list.

**RAiSERed\_plot**

```
RAiSERed.RAiSERed_plot(raised_list)
```

Plot of probability density function and Fourier filtered probability density function for radio AGNs in list.

**Parameters:** `raised_list` : *RAiSERed\_list* or *RAiSERed\_obj*

List of radio AGNs each stored in a *RAiSERed\_obj*, or a single element of the list. Radio AGNs can be selected from the list by name or index number; by default all elements in the list are plotted.

**Returns:** `plt_list` : *list* or *matplotlib.figure*

Return handle to matplotlib plot, or a list of handles if multiple radio AGNs are included in the list.

**RAiSERed\_zzplot**

```
RAiSERed.RAiSERed_zzplot(raised_list, legend_text=None, plot_type='default')
```

Plot of the correlation between the spectroscopic and radio continuum redshifts for calibrator radio AGNs in list.

**Parameters:** `raised_list` : *RAiSERed\_list* or *RAiSERed\_obj*

List of radio AGNs each stored in a *RAiSERed\_obj*. Radio AGNs can be selected from the list by name or index number; by default all elements in the list are plotted.

`legend_text` : *list* or *str*, *optional*

Specify legend text (if applicable) as a list of strings for up to three groups of radio AGNs.

`plot_type` : *str*, *optional*

Specify variable used to colour groups of radio AGNs. Options include 'default', 'lobes' and 'series'. If 'default' is selected all the AGNs are assumed to belong to the one group. If 'lobes' is selected the AGNs are grouped based on the final letter of the source name ('N' and 'E' or 'S' and 'W'). If 'series' is selected the AGNs are grouped based on the user defined integer in the series parameter of the *RAiSERed\_add* function. The default value is 'default'.

**Returns:** `plt_list` : *matplotlib.figure*

Return handle to matplotlib plot.

**Examples**

Create an empty list to add observed attributes of each radio AGNs.

```
>>> import RAiSERed as rr
>>> raised_list = rr.RAiSERed_list()
```

Add observed attributes for radio AGNs with known spectroscopic redshifts (minimum of five for calibration). Different accepted usage of the input parameters has been included for each source.

```
>>> rr.RAiSERed_add(raised_list, 'CygnusAE', 0.151, [5960, 450], [58.6, 0.4], 2.8,
[2.485, 0.009], [9.243, 0.017], specz=0.056075)
>>> rr.RAiSERed_add(raised_list, '3C20E', 0.178, [21.64, 0.13], [24.55, 0.22], 5.04,
[2.222, 0.001], [9.759, 0.001], specz=0.174, calib=True)
>>> rr.RAiSERed_add(raised_list, '3C244.1N', 1.78e8, [12.95, 0.65], [28.45, 0.40], 10.00,
[2.562, 0.005], [9.930, 0.022], specz=0.428)
>>> rr.RAiSERed_add(raised_list, 'PKS0529-549', 1.51e8, [2.78, 0.22], [0.6, 0.33],
[1.6, 5.0, 1000], [2.474, 0.005], [9.160, 0.014], specz=2.57)
>>> rr.RAiSERed_add(raised_list, 'USS1243+036', 151, [2.23, 0.18], [3, 0.115], [6.9, 0.8],
[2.739, 0.007], [9.005, 0.014], specz=3.57, calib=True)
```

Add observed attributes for additional radio AGNs with no known spectroscopic redshifts.

```
>>> rr.RAiSERed_add(raised_list, '3C388W', 178, [14.75, 0.74], [20.5, 0.8], 2.94,
[2.318, 0.004], [9.723, 0.015], calib=False)
>>> rr.RAiSERed_add(raised_list, 'USS1707+105', 0.151, [1.44, 0.12], [11.25, 0.115],
[13.5, 6.25, -1000], [2.528, 0.008], [8.963, 0.016])
```

Calculate redshift probability density function using optimal calibration from RAiSERed manuscript.

```
>>> rr.RAiSERed(raised_list, b1=0.76, b2=0.01, b3=-0.60, b4=-0.33)
```

Plot correlation between spectroscopic and radio continuum redshifts for calibrators (though we have used a user defined calibration above).

```
>>> rr.RAiSERed_zzplot(raised_list)
```

Plot redshift probability density functions for all radio AGNs in the list, or just USS1707+105.

```
>>> rr.RAiSERed_plot(raised_list)
```

```
>>> rr.RAiSERed_plot(raised_list['USS1707+105'])
```

Find radio continuum redshift and standard deviation for USS1707+105.

```
>>> print(raised_list['USS1707+105'].mean, raised_list['USS1707+105'].stdev)
```

Calibrate the RAISERed model using the calibrators in the list and calculate the redshift probability density function. This may take quite some time to run if numerous calibrators are used.

```
>>> b1, b2, b3, b4 = rr.RAiSERed(raised_list)
```

Plots of the redshift probability density functions and correlations between the spectroscopic and radio continuum redshifts are made using the `RAiSERed_plot()` and `RAiSERed_zzplot()` functions as before.