hpproj Documentation

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Contents

HealPixProjection is a project to allow easy and efficient projection of healpix maps onto planar grids. It can be used as a standalone program `hpproj.cutsky()`

```
$ cutsky 0.0 0.0 --mapfilenames HFI_SkyMap_857_2048_R2.00_full.fits
```

or as a python function

```
from hpproj import cutsky
result = cutsky([0.0, 0.0], maps={'HFI 857': {'filename': 'HFI_SkyMap_857_2048_R2.00_
↪full.fits'}})
```

or as a python class, for optimization when producting several cuts

```
from hpproj import CutSky, to_coord
cutsky = CutSky({'Planck 857': {'filename': 'HFI_SkyMap_857_2048_R2.00_full.fits'}})
result = cutsky.cut_fits(to_coord([0., 0.])
```

Note: For science applications requiring high photometric accuracy, we recommend the drizzlib software developed by CADE, which uses a flux-conserving drizzling method to reproject data between HEALPix and local WCS. Drizzlib is available as standalone software (IDL python) here: http://cade.irap.omp.eu/dokuwiki/doku.php?id=software . An online interface, drizzweb, is available here: http://drizzweb.irap.omp.eu/ .

You can also have a look into the `reproject.reproject_from_healpix()` function from the reproject package.

CHAPTER 1

Features

- Galactic and equatorial system supported
- All projection system from `wcs`
- Project several healpix maps at once, efficiently !
- Output in `fits`, `png` or `votable`
- Perform *n-dim projections* !

See *Basic Usage* for more information on how to use `cutsky`

CHAPTER 2

Installation

Install `hpproj` using pip :

```
$ pip install hpproj
```

or by running setuptools on source. For more information see the installation page.

CHAPTER 3

Contribute

- Issues Tracker
- Source Code

CHAPTER 4

Support

If you are having issues, please let us know.

CHAPTER 5

License

This project is licensed under the LGPL+3.0 license.

CHAPTER 6

Contents:

6.1 Installation

hpproj is tested against python 2.7 and 3.5 and can be installed using *pip* or from *source*

6.1.1 pip

```
$ pip install hpproj
```

This will install the latest release of hpproj

6.1.2 source

```
$ git clone https://git.ias.u-psud.fr/abeelen/hpproj.git
$ cd hpproj
$ python setup.py install
```

This will install the master tree of hpproj. It is probably wiser to checkout a specific version before installation

```
$ git clone https://git.ias.u-psud.fr/abeelen/hpproj.git
$ cd hpproj
$ git checkout 0.4
$ python setup.py install
```

6.1.3 Dependencies

hpproj require the following librairies

- numpy>=1.13

- matplotlib>=2.0
- astropy>=2.0
- healpy>=1.9
- photutils>=0.4

The specific versionning are those you are being used in the test suit. Both *pip* and *source* install should install those library if they are missing.

6.2 Basic Usage

Caution: All the healpix maps *must* have a proper header defining their :

- frame using the `COORDSYS` keyword,
- order using the `ORDERING` keyword.

However you can correct the headers in the construction of the list of maps

```
maps = [ {'HFI 100': {'filename': 'data/HFI_SkyMap_100_2048_R2.00_full.fits',
↪'COORDSYS': 'C'}}]
```

There is two main way to use `hpproj`, the first way is to use the standalone program on the command line, this will efficiently produce cuts for similar maps, or use it programmatically from within a python script or program which will offer an additional speed-up on high memory system.

6.2.1 From the command line - `cutsky`

The command line program is called *cutsky* and takes 3 arguments at minimum, the longitude and latitude of the desired projection (by default in `galactic` coordinate, but see below) and a list of healpix map to cut from :

```
$ cutsky 0.0 0.0 --mapfilenames data/HFI_SkyMap_100_2048_R2.00_full.fits  data/HFI_
↪SkyMap_857_2048_R2.00_full.fits
```

by default this will produce two `png` files centered on galactic longitude and latitude (0,0). Fits images of central photometries can be obtain using the `--fits` or `--phot` options. Help on `cutsky` can be obtain by

```
$ cutsky -h

usage: cutsky [-h] [--npix NPIX | --radius RADIUS] [--pixsize PIXSIZE]
              [--coordframe {galactic,fk5}]
              [--ctype {AZP,SZP,TAN,STG,SIN,ARC,ZPN,ZEA,AIR,CYP,CEA,CAR,MER,COP,COE,
↪COD,COO,SFL,PAR,MOL,AIT,BON,PCO,TSC,CSC,QSC,HPX,XPH}]
              [--mapfilenames MAPFILENAMES [MAPFILENAMES ...]] [--fits]
              [--png] [--votable aperture [aperture ...]] [--outdir OUTDIR] [-v | -q]␣
↪[--conf CONF]
              lon lat

Reproject the spherical sky onto a plane.

positional arguments:
  lon                   longitude of the projection [deg]
```

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```
  lat                   latitude of the projection [deg]

optional arguments:
  -h, --help            show this help message and exit
  --npix NPIX           number of pixels (default 256)
  --radius RADIUS       radius of the requested region [deg]
  --pixsize PIXSIZE     pixel size [arcmin] (default 1)
  --coordframe {galactic,fk5}
                        coordinate frame of the lon. and lat. of the
                        projection and the projected map (default: galactic)
  --ctype {AZP,SZP,TAN,STG,SIN,ARC,ZPN,ZEA,AIR,CYP,CEA,CAR,MER,COP,COE,COD,COO,SFL,
↪PAR,MOL,AIT,BON,PCO,TSC,CSC,QSC,HPX,XPH}
                        any projection code supported by wcslib (default:TAN)

input maps:
  one of the two options must be present
  --mapfilenames MAPFILENAMES [MAPFILENAMES ...]
                        absolute path to the healpix maps
  --conf CONF           absolute path to a config file

output:
  --fits                output fits file
  --png                 output png file (Default: True if nothing else)
  --votable aperture [aperture ...]
                        list of aperture [arcmin] to make circular aperture photometry
  --outdir OUTDIR       output directory (default:.)

general:
  -v, --verbose         verbose mode
  -q, --quiet           quiet mode
```

It takes two float arguments, the latitude and longitude center of the requested projection, either in galactic or equatorial coordinate frame (controled by the `--coordframe` option) and a list of healpix maps, either on the command line with the `--mapfilenames` argument or describe in a config file (with the `--conf` option). Several other optional arguments can also be set like `--npix` the number of pixels, their size (`--pixsize`) or the projection type `--ctype`.

The cutted maps can be saved as fits (`--fits`) or png (`--png`) and central circular aperture photometry can be performed and saved as a votable (`--votable aperture`). The output products directory can be tune using the `--outdir` option. All theses options can also be provided by the config file.

The config file follows a simple ini syntax with a global section `[cutsky]` to gather all previous options. The rest of the sections is used to describe the healpix maps used by `cutsky`. The section name `[test]` will be used as a legend and index by `cutsky`.

```
[cutsky]
npix = 256
pixsize = 2
coordframe = galactic
png = True

[SMICA]
filename = hpproj/data/CMB_I_SMICA_128_R2.00.fits
docut = False

[HFI 100]
filename = hpproj/data/HFI_SkyMap_100_128_R2.00_RING.fits
```

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```
[HFI 857]
filename = hpproj/data/HFI_SkyMap_857_128_R2.00_NESTED.fits
docut = True
docontour = True
```

6.2.2 As a function call - `cutsky()`

It is also possible to call `cutsky` from a python program or script, as a function. You first need to define a list of maps on which to perform the cuts, as list of tuple with at minimum `(filename.fits, {'legend': "legend"))` given the full path to the healpix map, and a dictionnary with a least the key `legend`

```
from hpproj import cutsky

maps = [('data/HFI_SkyMap_100_2048_R2.00_full.fits', {'legend': 'HFI 100', 'aperture
↪': [1, 2, 3]}),
        ('data/HFI_SkyMap_857_2048_R2.00_full.fits', {'legend': 'HFI 857', 'docontour
↪': True})]

result = cutsky([0.0, 0.0], maps=maps)
```

The first argument is the latitude and longitude of the requested maps, by default in `galactic` frame (see the `coordframe` keyword), and the `maps` list define the healpix maps.

This will produce a list of dictionnaries containing 4 keys:

- `legend`,
- `fits` an ~astropy.io.fits.ImageHDU,
- `png`, a b61encoded png image of the fits
- `phot`, the corresponding photometry

Additionnal parameters can by passed to the function :

- `patch=[256,1]` : the size of the patch in pixel, and the size of the pixels in arcmin
- `ctype='TAN'` : the desired type of projection

6.2.3 As an object - `CutSky`

It is however more efficient to use cutsky as an object :

```
from hpproj import CutSky, to_coord

maps = [('data/HFI_SkyMap_100_2048_R2.00_full.fits', {'legend': 'HFI 100', 'aperture
↪': [1, 2, 3]}),
        ('data/HFI_SkyMap_857_2048_R2.00_full.fits', {'legend': 'HFI 857', 'docontour
↪': True})]

cutsky = CutSky(maps, low_mem=False)

coord = to_coord([0.0,0.0])
result = cutsky.cut_fits(coord) # Will only produce the 'fits' key
```

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```
result = cutsky.cut_png(coord)  # Will only produce the 'png' key (and 'fits' if␣
↪absent)
result = cutsky.cut_phot(coord) # Will only produce the 'phot' key (and fits' if␣
↪absent)
```

The result product should be similar to the `cutsky()` function. However with the `low_mem` keyword the healpix maps will be read only once in memory, for all `cut_*` calls. Similar to `cutsky()` several keyword parameters can be passed to `CutSky()` :

- `npix=256` : the size of the patch in pixels
- `pixsize=1` : the size of the pixels in arcmin
- `ctype='TAN'`: the desired type of projection

6.2.4 As internal calls - `hp_helper`

Alternatively if you simply want to get a projected array, you can use the `hp_project()` function

```
from astropy.io import fits
from astropy.coordinates import SkyCoord
import healpy as hp
from hpproj import hp_project

hp_data, hp_header = hp.read_map('data/HFI_SkyMap_100_2048_R2.00_full.fits', h=True)
hp_header = fits.Header(hp_header)

hdu = hp_project(hp_data, hp_header, SkyCoord(0, 0, unit='deg'))
```

Or, if you prefer to get full control, you can also use the internal functions like `build_wcs()` and `hp_to_wcs()`

```
from astropy.io import fits
import healpy as hp
import hpproj as hpp

hp_data, hp_header = hp.read_map('data/HFI_SkyMap_100_2048_R2.00_full.fits', h=True)
hp_header = fits.Header(hp_header)
hp_hdu = fits.ImageHDU(hp_data, hp_header)

w = hpp.build_wcs(0, 0)

proj_map = hpp.hp_to_wcs(hp_data, hp_header, w)
```

Note that both *hp_project* and *hp_to_wcs* accept either an *~astropy.io.fits.ImageHDU*, or both *hp_data, hp_header*

6.3 *n-d* Projections !

hpproj allow for *n-d* projections, for *d=3* to *d=0*

Caution: `healpy` by default change any healpix map into the RING pixelization scheme without changing its header. Be sure to read the maps with the *nest=None*

First let's setup the dataset :

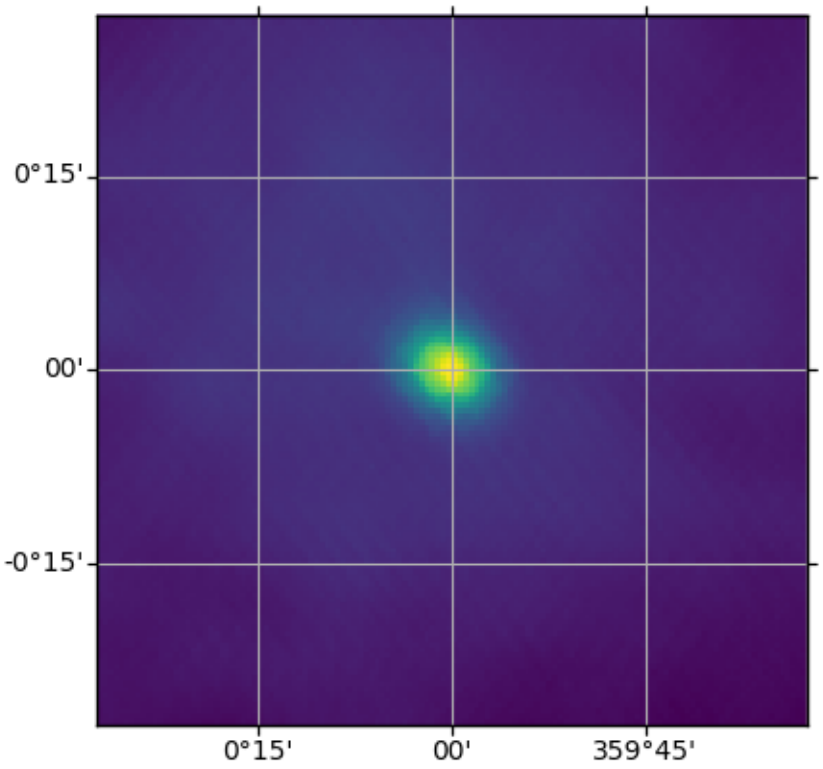
```
import numpy as np
import matplotlib.pyplot as plt
import healpy as hp

from astropy.io import fits
from astropy.coordinates import SkyCoord
from astropy.utils.data import download_file
from astropy.wcs import WCS
from astropy.table import Table

from hpproj import hp_stack

# Retrieve the Planck 857 GHz all sky map
irsa_url = 'http://irsa.ipac.caltech.edu/data/Planck/release_2/all-sky-maps/maps/'
url = irsa_url + 'HFI_SkyMap_857_2048_R2.02_full.fits'
filename = download_file(url, cache=True)

hp_data, hp_header = hp.read_map(filename, h=True, nest=None)
hp_hdu = fits.ImageHDU(hp_data, fits.Header(hp_header))
hp_hdu.header['UNIT'] = 'MJy/sr'

# Fetch the PCCS catalog
cds_url = 'http://cdsarc.u-strasbg.fr/ftp/cats/J/A+A/594/A26/fits/'
url = cds_url + 'PCCS_857_R2.01.fits'

PCCS = Table.read(download_file(url, cache=True))
# Select a few sources
PCCS = PCCS[np.abs(PCCS['GLAT']) > 30]
PCCS = PCCS[:500]
```

6.3.1 3-d projections

hpproj allow for stacking in the healpix map

```
coords = SkyCoord(PCCS['RA'].data, PCCS['DEC'].data, unit="deg")
pixsize = hp.nside2resol(hp_hdu.header['NSIDE'], arcmin=True) /60 /4
hdu = hp_stack(hp_hdu, coords, pixsize=pixsize, shape_out=(128, 128))
```

hdu is an `astropy.io.fits.ImageHDU` containing the stack of all the requested positions. One can also use the *keep* option to retrieve all the individual maps



6.3.2 2.5-d projections

Using some more in-depth routine of *hpproj*, it is possible to place 2 sources at a relative given position on a map

```
from astropy.visualization import ImageNormalize, HistEqStretch

from hpproj import build_wcs_2pts
from hpproj import hp_to_wcs

coord_LMC = SkyCoord("05:23:34.60", "-69:45:22.0", unit=(u.hourangle, u.deg))
coord_SMC = SkyCoord("00h52m38s", "-72:48:01", unit=(u.hourangle, u.deg))

pair_coord = (coord_LMC, coord_SMC)

relative_pos = [0.3, 0.7]
shape_out = (512, 1024)

wcs = build_wcs_2pts(pair_coord, shape_out=shape_out, relative_pos=relative_pos)
img = hp_to_wcs(hp_hdu, wcs, shape_out)

norm = ImageNormalize(stretch=HistEqStretch(img))

fig = plt.figure()
ax = fig.add_subplot(1, 1, 1, projection=wcs)
```

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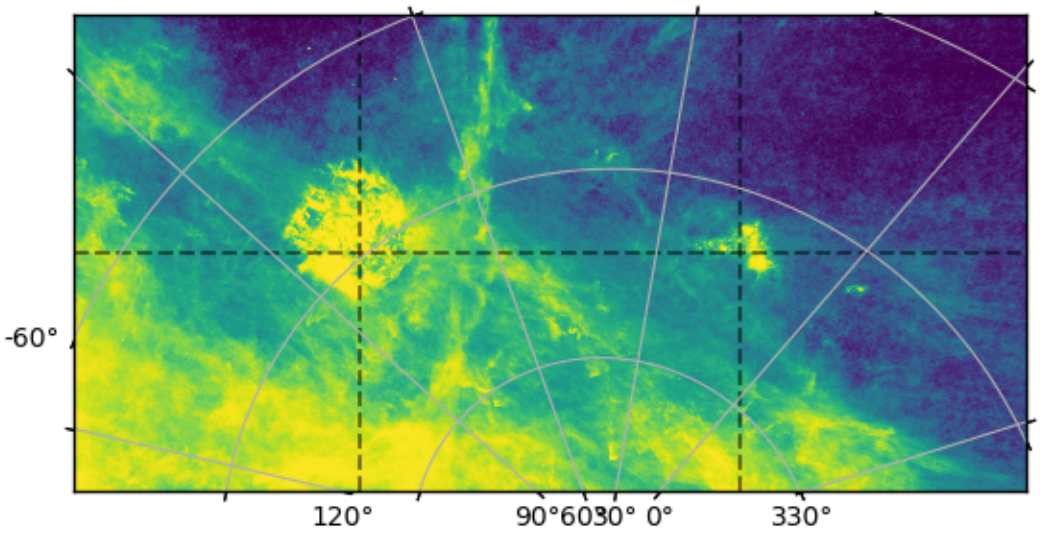
```
ax.imshow(img, origin='lower', interpolation='none', norm=norm)
ax.grid()

ax.axhline(0.5 * img.shape[0], linestyle='--', c='k', alpha=0.5)
for pos in relative_pos:
    ax.axvline(pos * img.shape[1], linestyle='--', c='k', alpha=0.5)
```



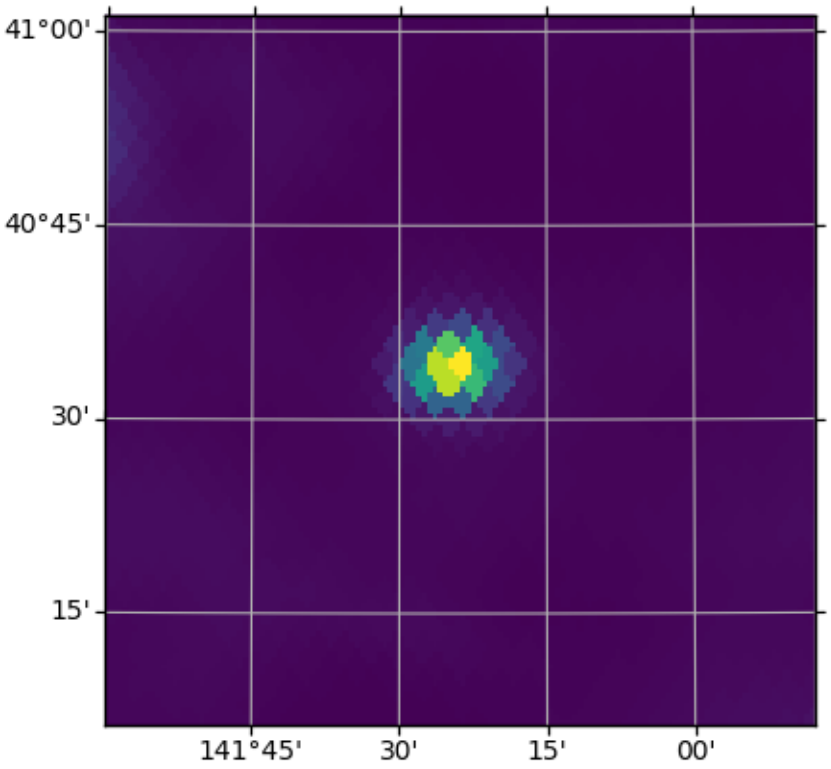
6.3.3 2-d Projections

This is the most common projection, from an healpix map to a 2D map

```
from hpproj import hp_project

coord = SkyCoord(141.397513059, 40.5638050454, unit="deg", frame="galactic")
pixsize = hp.nside2resol(hp_hdu.header['NSIDE'], arcmin=True) / 60 / 4
hdu = hp_project(hp_hdu, coord, pixsize=pixsize, shape_out=(128, 128))
```

hdu is then an `astropy.io.fits.ImageHDU` containing the requested region on the sky and it's corresponding header, which can be easily plotted with, for e.g., *matplotlib*



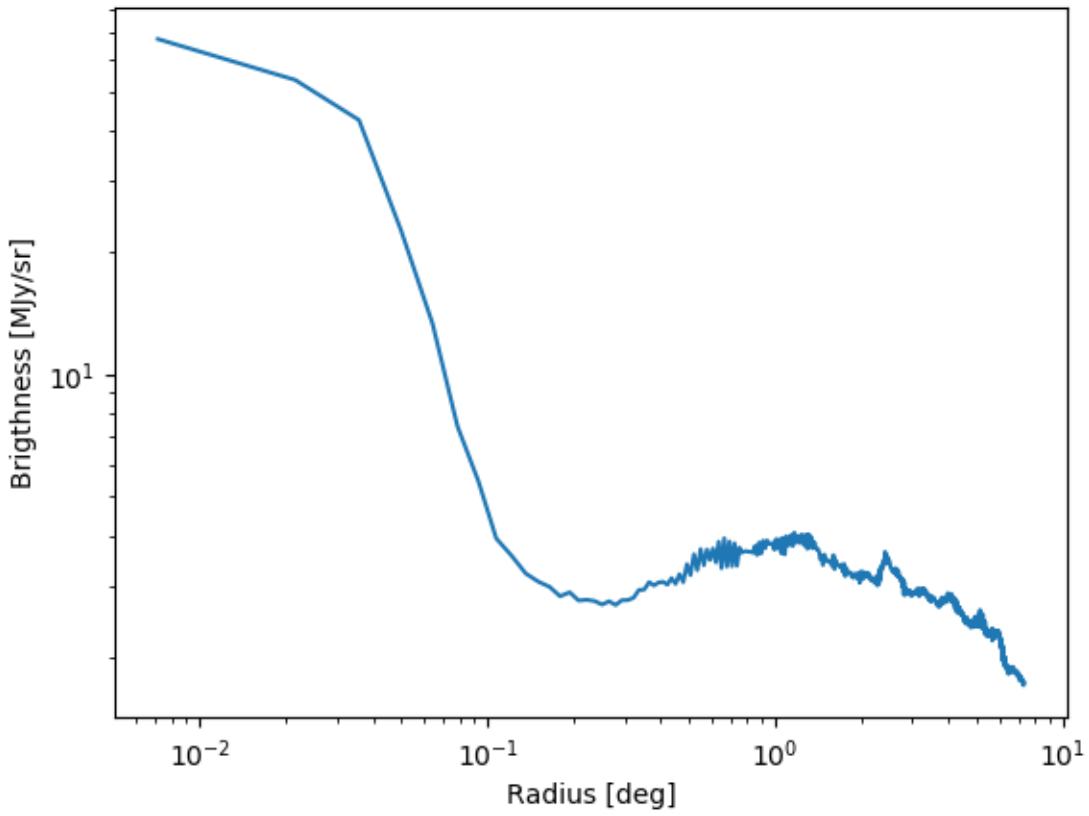
6.3.4 1-d Projections

The 1-d projection goes from an healpix map to a intensity profile

```
from hpproj import hp_profile

coord = SkyCoord(202.4865871680179, 47.181795866475426, unit="deg")
hdu = hp_profile(hp_hdu, coord)
```

hdu is then an `astropy.io.fits.ImageHDU` with the profile centered on the requested coordinates



6.3.5 0-d Projections

The 0-d projection goes from an healpix map to an aperture photometry, of a given position

```
from hpproj import hp_photometry
from astropy.coordinates import SkyCoord, Angle

coord = SkyCoord(202.4865871680179, 47.181795866475426, unit="deg")
apertures = Angle(hp.nside2resol(hp_hdu.header['NSIDE'], arcmin=True) / 60, "deg") *␣
↪[7, 10, 15]
result = hp_photometry(hp_hdu, coord, apertures=apertures)
```

result is then an `astropy.table.Table` with the aperture photometry

```
Out[1]:
<Table length=1>
brigthness    background   n_pix
MJy / sr      MJy / sr
float64       float64      int64
------------- ------------ -----
2.51999285723 1.2330693081   151
```

6.4 Visualization

The HealPixProjection routines can easily be used to display a full sky map with different projections. In the `hpproj.visu` module, several projection have been implemented

```
import matplotlib.pyplot as plt
import numpy as np
import healpy as hp
from astropy.wcs import WCS
from hpproj import mollview

# Ring like healpix map
nside = 2**6
hp_map = np.arange(hp.nside2npix(nside))
hp_header = {'NSIDE': nside,
             'ORDERING': 'RING',
             'COORDSYS': 'G'}

# Projection of the map and plotting
_ = mollview(hp_map, hp_header)
fig = plt.figure()
ax = fig.add_subplot(1,1,1, projection=WCS(_.header))
ax.imshow(_.data, origin='lower', interpolation='none')
ax.grid()
ax.set_title('mollview')
```

Note that these maps have a proper `WCS` header and thus can be easily used to overplot markers and artists.

Other classical projections have been implemented

6.5 API

6.5.1 cutsky

6.5.2 helpers

6.5.3 visu

CHAPTER 7

Indices and tables

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