hips Documentation

Release 0.3.dev357

HiPS developers

Jul 24, 2018

User documentation

This is the documentation page for `hips`. A Python astronomy package for HiPS : Hierarchical Progressive Surveys.

Part I

About

CHAPTER 1

Description

HiPS (Hierarchical Progressive Surveys) is a way to store large astronomical survey sky image and catalog datasets on servers (such as HiPS at CDS), that allows clients to efficiently fetch only the image tiles or catalog parts for a given region of the sky they are interested in. Similar to Google maps, but for astronomy (see the HiPS paper).

This is a Python package to fetch and draw HiPS data.

It was just started in summer of 2017 and isn't stable or feature complete yet. Feedback and contributions welcome!

CHAPTER 2

Links

- Code : https://github.com/hipspy/hips
- Docs : https://hips.readthedocs.io
- Contributors : https://github.com/hipspy/hips/graphs/contributors
- Releases: https://pypi.python.org/pypi/hips

CHAPTER 3

Other resources

- GSoC 2017 blog by Adeel: https://adl1995.github.io
- HiPS at CDS (contains a list and preview of available HiPS data)
- HiPS paper
- HiPS IVOA recommendation
- A Jupyter widget for Aladin Lite: https://github.com/cds-astro/ipyaladin
- Small example HiPS datasets we use for testing and docs examples: https://github.com/hipspy/hips-extra

(If you have a HiPS-related webpage or tool or resource you'd like mentioned here, let us know!)

CHAPTER 4

Thanks

This package is being developed as part of Google Summer of Code 2017 program by Adeel Ahmad, with Thomas Boch (CDS, Strasbourg) and Christoph Deil (MPIK, Heidelberg) as mentors. We would like to thank Google, CDS, MPIK for their support!

If you're interested, you should follow Adeel's blog: https://adl1995.github.io/

Also: thanks to the Astropy team for developing and maintaining the affiliated package-template and the ci-helpers! The recently introduced cookie-cutter makes it even quicker to set up a new package like this one in a good, maintainable way.

Part II

Installation

The **hips** package works with Python 3.6 or later, on Linux, MacOS and Windows.

Installing the latest stable version is possible either using pip or conda.

How to install the latest development version is desribed on the *Develop* page.

CHAPTER 5

Using pip

To install hips with pip from PyPI, run:

```
pip install hips --no-deps
```

Note: The `--no-deps` flag is optional, but highly recommended if you already have Numpy installed, since otherwise pip will sometimes try to "help" you by upgrading your Numpy installation, which may not always be desired.

CHAPTER 6

Using conda

To install hips with Anaconda from the conda-forge channel on anaconda.org simply run:

```
conda install -c conda-forge hips
```

CHAPTER 7

Check installation

To check if you have `hips` installed, where it was installed and which version you have:

```
$ python
>>> import hips  # doctest: +SKIP
>>> hips.__version__  # doctest: +SKIP
# -> prints which version you have
>>> hips  # doctest: +SKIP
# -> prints where hips is installed
```

To see if you have the latest stable, released version of `hips`, you can find that version here:

- https://pypi.python.org/pypi/hips
- https://anaconda.org/conda-forge/hips

Next you could try running the examples at *Getting started* and see if you get the expected output.

It's usually not necessary, but if you find that your `hips` installation gives errors or unexpected results for examples that should work, you can run the `hips` automated tests via:

```
python -c 'import hips; hips.test()'
```

For more information on automated tests, see the *Develop* page.

CHAPTER 8

Dependencies

The `hips` package has the following requirements:

- Python 3.6 or later!
- Numpy 1.11 or later
- Astropy 1.2 or later
- astropy-healpix 0.2 or later
- scikit-image 0.12 or later. (Older versions could work, but aren't tested.)
- Pillow 4.0 or later. (Older versions could work, but aren't tested.) Pillow is the friendly Python Imaging Library (`PIL`) fork, for JPEG and PNG tile I/O.

In addition, the following packages are needed for optional functionality:

- Matplotlib 2.0 or later. Used for plotting in examples.
- tqdm. Used for showing progress bar either on terminal or in Jupyter notebook.
- aiohttp. Used for fetching HiPS tiles.

We have some info at *Why only Python 3?* on why we don't support legacy Python (Python 2).

Part III

Getting started

This is a quick getting started guide for the Python `hips` package.

CHAPTER 9

Make a sky image

To draw a sky image from HiPS image tiles with the `hips` package, follow the following three steps:

1. Specify the sky image geometry you want by creating a `WCSGeometry` object:

```
from astropy.coordinates import SkyCoord
from hips import WCSGeometry

geometry = WCSGeometry.create(
     skydir=SkyCoord(0, 0, unit='deg', frame='galactic'),
     width=2000, height=1000, fov="3 deg",
     coordsys='galactic', projection='AIT',
)
```

2. Specify the HiPS survey you want. You just need to provide a valid HiPS survey ID.

   A good address that lists available HiPS data is http://aladin.u-strasbg.fr/hips/list

```
hips_survey = 'CDS/P/DSS2/red'
```

3. Call the `make_sky_image` function to fetch the HiPS data and draw it, returning an object of `HipsDrawResult`. By default a progress bar is shown for fetching and drawing HiPS tiles. For batch processing, this can be turned off by passing a keyword argument: `progress_bar=False`:

```
from hips import make_sky_image
result = make_sky_image(geometry, hips_survey, 'fits')
```

Of course, you could change the parameters to chose any sky image geometry and available HiPS survey you like!

CHAPTER 10

Work with the result

The `HipsDrawResult` object from the last section makes it easy for you to plot, save or analyse the sky image. To generate a quick-look plot of the sky image, with rectangles outlining the HiPS tiles that were fetched and drawn to create the sky image:

```
result.plot()
```

this will result in the following plot:

To save the sky image to a file:

```
result.write_image('my_image.fits')
```

To analyse the data, or make a publication-quality plot, you can get the sky image pixel data as a `numpy.ndarray`:

```
>>> result.image
```

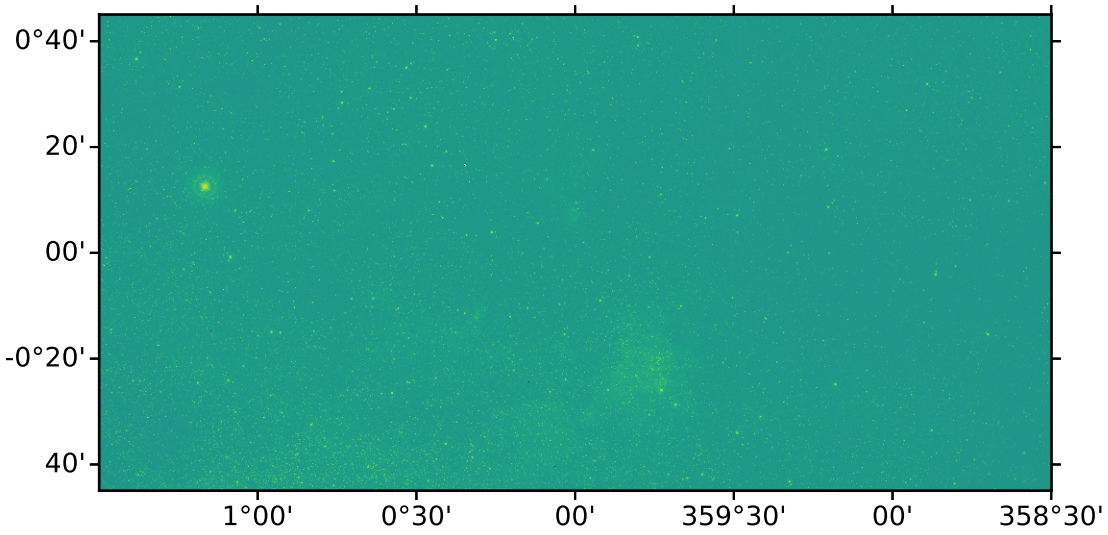
and the sky image `astropy.wcs.WCS` mapping pixel to sky coordinates via:

```
>>> result.geometry.wcs
```

To print out summary information about the result:

```
>>> print(result)
```

The `HipsDrawResult` object also gives access to the `HipsTile` objects that were used for drawing the sky image, as well as other things.


0°40'
20'
00'
-0°20'
40'
1°00'
0°30'
00'
359°30'
00'
358°30'

CHAPTER 11

Plot using Astropy visualization toolkit

Astropy provides a framework for plotting astronomical images with coordinates. It builds on top of Matplotlib and provides functionalities such as image normalization (scaling and stretching), smart histogram plotting, RGB color image creation from separate images. The framework also allows for customization of plotting styles.

The example below is for the FITS format and controls the stretch of the image through normalization. For FITS tiles, the data type is either `int16` or `float32`:

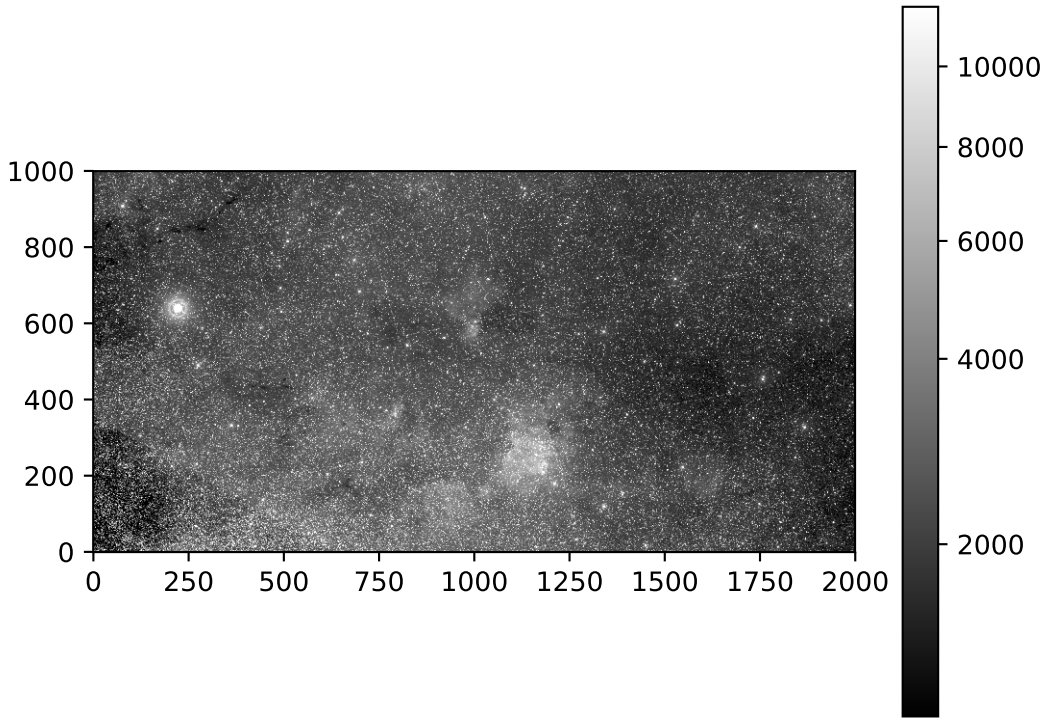
```
import matplotlib.pyplot as plt
from astropy.visualization.mpl_normalize import simple_norm

fig = plt.figure()
ax = fig.add_subplot(1, 1, 1)
im = ax.imshow(result.image, origin='lower', norm=norm, cmap='gray')
fig.colorbar(im)
```

RGB tiles can be plotted in much the same way as above, however, it is uncommon to apply an extra stretch in this case. For `jpg` and `png` tiles, the data type is `uint8`.

Note: For `png` tiles, there are four channel i.e. RGBA. The alpha channel is used for controlling the transparency of the image.

The example provided here is trivial. Astropy provides numerous other features, customizability options, and in-depth examples. Please see their documentation at: https://docs.astropy.org/en/stable/visualization

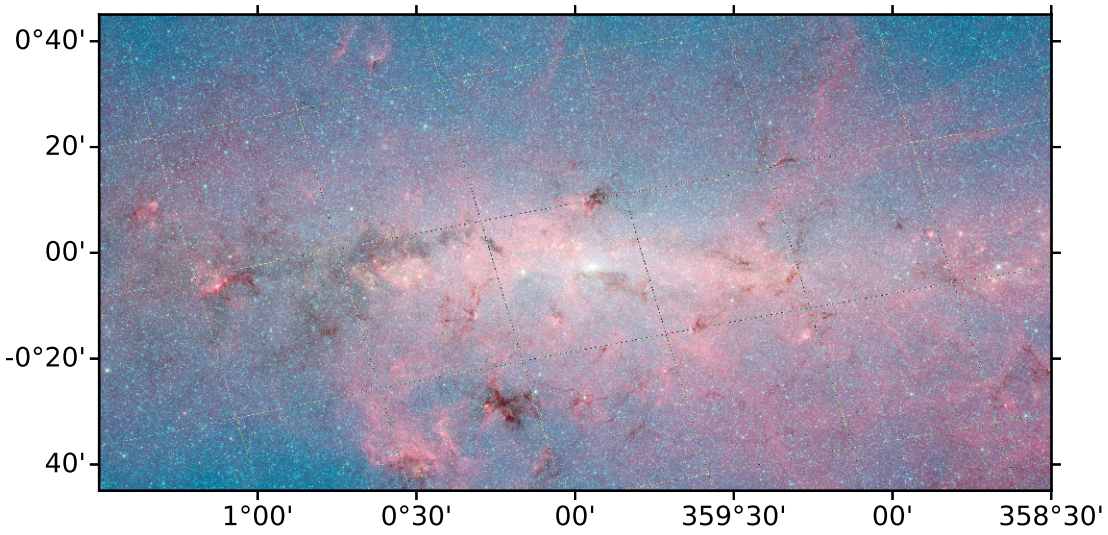

1000
800
600
400
200
0
0
250
500
750
1000
1250
1500
1750
2000
10000
8000
6000
4000
2000

CHAPTER 12

Make a color sky image

HiPS supports color images in `jpg` and `png` format. Making a color sky image works the same as the grayscale image example above, except that you get back a 3-dim Numpy array with `(R, G, B)` channels for `jpg` or `(R, G, B, A)` channels (`A` is transparency) for `png`.

Here's an example using `jpg` and http://alasky.u-strasbg.fr/Fermi/Color:


0°40'
20'
00'
-0°20'
40'
1°00'
0°30'
00'
359°30'
00'
358°30'

CHAPTER 13

HiPS data

We plan to implement functionality to manage HiPS data, i.e. download it and cache it on a local disk. This isn't available yet, at the moment we simply use Python lists of `HipsTile` objects, which have a `read` method for a given filename and a `fetch` method for a given URL.

CHAPTER 14

More advanced examples

This package is under heavy development, it's changing quickly.

We'll add advanced examples and detailed documentation once things have stabilised a bit.

For now, if you know Python, you can look at the code and tests to see what's available: https://github.com/hipspy/hips

CHAPTER 15

What next?

That's it, now you've seen the main features of the `hips` package. Note that there is API documentation explaining all available functions, classes and parameters.

If you have any questions, or find something not working or a missing feature, please get in touch by posting on our Github issue tracker.

Part IV

Reference/API

CHAPTER 16

hips Package

A Python astronomy package for HiPS : Hierarchical Progressive Surveys.

At the moment a client for HiPS images, but other contributions (HiPS catalogs or HiPS image generation) welcome!

- Code : https://github.com/hipspy/hips
- Docs : https://hips.readthedocs.io
- License : BSD-3 (see licenses folder for license file)

16.1 Functions

fetch_tiles(tile_metas, hips_survey, ...)	Fetch a list of HiPS tiles.
healpix_to_hips(hpx_data, tile_width, base_path)	Convert HEALPix image to HiPS.
healpix_to_hips_tile(hpx_data, tile_width, ...)	Create single hips tile from healpix data given a tile index.
make_sky_image(geometry, ...)	Make sky image: fetch tiles and draw.
test([package, test_path, args, plugins, ...])	Run the tests using py.test.

16.1.1 fetch_tiles

hips.**fetch_tiles**(*tile_metas: List[hips.tiles.tile.HipsTileMeta], hips_survey: hips.tiles.survey.HipsSurveyProperties, progress_bar: bool = True, n_parallel: int = 5, timeout: float = 10, fetch_package: str = 'urllib'*) → List[hips.tiles.tile.HipsTile]

Fetch a list of HiPS tiles.

This function fetches a list of HiPS tiles based on their URLs, which are generated using `hips_survey` and `tile_metas`.

The tiles are then fetched asynchronously using `urllib` or `aiohttp`.

Parameters

tile_metas : list

Python list of `HipsTileMeta`

hips_survey : `HipsSurveyProperties`

HiPS survey properties

progress_bar : bool

Show a progress bar for tile fetching and drawing

n_parallel : int

Number of tile fetch web requests to make in parallel

timeout : float

Seconds to timeout for fetching a HiPS tile

fetch_package : {'urllib', 'aiohttp'}

Package to use for fetching HiPS tiles

Returns

tiles : list

A Python list of `HipsTile`

Examples

Define a list of tiles we want:

```
from hips import HipsSurveyProperties, HipsTileMeta
from hips import fetch_tiles
url = 'http://alasky.unistra.fr/DSS/DSS2Merged/properties'
hips_survey = HipsSurveyProperties.fetch(url)
tile_indices = [69623, 69627, 69628, 69629, 69630, 69631]
tile_metas = []
for healpix_pixel_index in tile_indices:
    tile_meta = HipsTileMeta(
       order=7,
       ipix=healpix_pixel_index,
       frame=hips_survey.astropy_frame,
       file_format='fits',
    )
    tile_metas.append(tile_meta)
```

Fetch all tiles (in parallel):

```
tiles = fetch_tiles(tile_metas, hips_survey)
```

16.1.2 healpix_to_hips

hips.**healpix_to_hips**(*hpx_data*, *tile_width*, *base_path*, *file_format='fits'*)

Convert HEALPix image to HiPS.

Parameters

hpx_data : `ndarray`

Healpix data stored in the "nested" scheme.

tile_width : int

Width of the hips tiles.

base_bath : str or `Path`

Base path.

file_format : {'fits', 'jpg', 'png'}

File format to store the hips in.

16.1.3 healpix_to_hips_tile

hips.**healpix_to_hips_tile**(*hpx_data*, *tile_width*, *tile_idx*, *file_format*) → hips.tiles.tile.HipsTile

Create single hips tile from healpix data given a tile index.

Parameters

hpx_data : `ndarray`

Healpix data stored in the "nested" scheme.

tile_width : int

Width of the hips tile.

tile_idx : int

Index of the hips tile.

file_format : {'fits', 'jpg', 'png'}

File format to store the hips tile in.

Returns

hips_tile : `HipsTile`

Hips tile object.

16.1.4 make_sky_image

hips.**make_sky_image**(*geometry: Union[dict, hips.utils.wcs.WCSGeometry], hips_survey: Union[str, _ForwardRef('HipsSurveyProperties')], tile_format: str, precise: bool = False, progress_bar: bool = True, fetch_opts: dict = None*) → hips.draw.ui.HipsDrawResult

Make sky image: fetch tiles and draw.

The example for this can be found on the *Getting started* page.

Parameters

geometry : dict or `WCSGeometry`

Geometry of the output image

hips_survey : str or `HipsSurveyProperties`

HiPS survey properties

tile_format : {'fits', 'jpg', 'png'}

Format of HiPS tile to use (some surveys are available in several formats, so this extra argument is needed)

precise : bool

Use the precise drawing algorithm

progress_bar : bool

Show a progress bar for tile fetching and drawing

fetch_opts : dict

Keyword arguments for fetching HiPS tiles. To see the list of passable arguments, refer to `fetch_tiles`

Returns

result : `HipsDrawResult`

Result object

16.1.5 test

hips.**test**(*package=None*, *test_path=None*, *args=None*, *plugins=None*, *verbose=False*, *pastebin=None*, *remote_data=False*, *pep8=False*, *pdb=False*, *coverage=False*, *open_files=False*, ***kwargs*)

Run the tests using py.test. A proper set of arguments is constructed and passed to pytest.main.

Parameters

package : str, optional

The name of a specific package to test, e.g. 'io.fits' or 'utils'. If nothing is specified all default tests are run.

test_path : str, optional

Specify location to test by path. May be a single file or directory. Must be specified absolutely or relative to the calling directory.

args : str, optional

Additional arguments to be passed to pytest.main in the `args` keyword argument.

plugins : list, optional

Plugins to be passed to pytest.main in the `plugins` keyword argument.

verbose : bool, optional

Convenience option to turn on verbose output from py.test. Passing True is the same as specifying `'-v'` in `args`.

pastebin : {'failed','all',None}, optional

Convenience option for turning on py.test pastebin output. Set to `'failed'` to upload info for failed tests, or `'all'` to upload info for all tests.

remote_data : bool, optional

Controls whether to run tests marked with @remote_data. These tests use online data and are not run by default. Set to True to run these tests.

pep8 : bool, optional

Turn on PEP8 checking via the pytest-pep8 plugin and disable normal tests. Same as specifying `'--pep8 -k pep8'` in `args`.

pdb : bool, optional

Turn on PDB post-mortem analysis for failing tests. Same as specifying `'--pdb'` in `args`.

coverage : bool, optional

Generate a test coverage report. The result will be placed in the directory htmlcov.

open_files : bool, optional

Fail when any tests leave files open. Off by default, because this adds extra run time to the test suite. Requires the psutil package.

parallel : int, optional

When provided, run the tests in parallel on the specified number of CPUs. If parallel is negative, it will use the all the cores on the machine. Requires the pytest-xdist plugin installed. Only available when using Astropy 0.3 or later.

kwargs

Any additional keywords passed into this function will be passed on to the astropy test runner. This allows use of test-related functionality implemented in later versions of astropy without explicitly updating the package template.

16.2 Classes

HipsDrawResult(image, geometry, tile_format, ...)	HiPS draw result object (sky image and more).
HipsPainter(geometry, ...)	Paint a sky image from HiPS image tiles.
HipsSurveyProperties(data)	HiPS properties container.
HipsSurveyPropertiesList(data)	HiPS survey properties list.
HipsTile(meta, raw_data)	HiPS tile container.
HipsTileAllskyArray(meta, raw_data)	All-sky tile array container.
HipsTileMeta(order, ipix, file_format, ...)	HiPS tile metadata.
WCSGeometry(wcs, width, height)	Sky image geometry: WCS and image shape.

16.2.1 HipsDrawResult

class hips.**HipsDrawResult**(*image: numpy.ndarray, geometry: hips.utils.wcs.WCSGeometry, tile_format: str, tiles: List[hips.tiles.tile.HipsTile], stats: dict*)

Bases: object

HiPS draw result object (sky image and more).

Parameters

image : ndarray

Sky image (the main result)

geometry : WCSGeometry

WCS geometry of the sky image

tile_format : {'fits', 'jpg', 'png'}

Format of HiPS tile

tiles : list

Python list of HipsTile objects that were used

stats : dict

Information including time for fetching and drawing HiPS tiles

Methods Summary

from_painter(painter)	Make a HipsDrawResult from a HipsTilePainter.
plot(show_grid)	Plot the all sky image and overlay HiPS tile outlines.
report()	Print a brief report for the fetched data.
write_image(filename, overwrite)	Write image to file.

Methods Documentation

classmethod from_painter(*painter: hips.draw.paint.HipsPainter*) → hips.draw.ui.HipsDrawResult
Make a HipsDrawResult from a HipsTilePainter.

plot(*show_grid: bool = False*) → None
Plot the all sky image and overlay HiPS tile outlines.

Parameters
show_grid : bool

Enable grid around HiPS tile boundaries

Uses 'astropy.visualization.wcsaxes'.

report() → None
Print a brief report for the fetched data.

write_image(*filename: str*, *overwrite: bool = False*) → None
Write image to file.

Parameters
filename : str

Filename

overwrite : bool

Overwrite the output file, if it exists

16.2.2 HipsPainter

class hips.**HipsPainter**(*geometry: Union[dict, hips.utils.wcs.WCSGeometry], hips_survey: Union[str, hips.tiles.survey.HipsSurveyProperties], tile_format: str, precise: bool = False, progress_bar: bool = True, fetch_opts: dict = None*)
Bases: object

Paint a sky image from HiPS image tiles.

Paint HiPS tiles onto a ky image using a simple projective transformation method. The algorithm implemented is described here: *HiPS tile drawing*.

Parameters
geometry : dict or WCSGeometry

An object of WCSGeometry

hips_survey : str or HipsSurveyProperties

HiPS survey properties

tile_format : {'fits', 'jpg', 'png'}

Format of HiPS tile

precise : bool

Use the precise drawing algorithm

progress_bar : bool

Show a progress bar for tile fetching and drawing

fetch_opts : dict

Keyword arguments for fetching HiPS tiles. To see the list of passable arguments, refer to `fetch_tiles`

Examples

```
>>> from astropy.coordinates import SkyCoord
>>> from hips import WCSGeometry
>>> from hips import HipsSurveyProperties
>>> from hips import HipsPainter
>>> geometry = WCSGeometry.create(
...     skydir=SkyCoord(0, 0, unit='deg', frame='icrs'),
...     width=2000, height=1000, fov='3 deg',
...     coordsys='icrs', projection='AIT',
... )
>>> url = 'http://alasky.unistra.fr/DSS/DSS2Merged/properties'
>>> hips_survey = HipsSurveyProperties.fetch(url)
>>> painter = HipsPainter(geometry, hips_survey, 'fits')
>>> painter.draw_hips_order
7
>>> painter.run()
>>> painter.image.shape
(1000, 2000)
```

Attributes Summary

`draw_hips_order`	Compute HiPS tile order matching a given image pixel size.
`image`	Computed sky image (`ndarray`).
`tile_indices`	Get list of index values for HiPS tiles.
`tiles`	List of `HipsTile` (cached on multiple access).

Methods Summary

`draw_all_tiles`()	Make an empty sky image and draw all the tiles.
`make_tile_list`()	
`plot_mpl_hips_tile_grid`()	Plot output image and HiPS grid with matplotlib.
`projection`(tile)	Estimate projective transformation on a HiPS tile.
`run`()	Draw HiPS tiles onto an empty image.
`warp_image`(tile)	Warp a HiPS tile and a sky image.

Attributes Documentation

draw_hips_order
Compute HiPS tile order matching a given image pixel size.

image
Computed sky image (ndarray).

- The dtype is always chosen to match the tile dtype. This is uint8 for JPG or PNG tiles, and can be e.g. int16 or float32 for FITS tiles.
- The output shape is documented here: shape.

tile_indices
Get list of index values for HiPS tiles.

tiles
List of HipsTile (cached on multiple access).

Methods Documentation

draw_all_tiles()
Make an empty sky image and draw all the tiles.

make_tile_list()

plot_mpl_hips_tile_grid() → None
Plot output image and HiPS grid with matplotlib.

This is mainly useful for debugging the drawing algorithm, not something end-users will call or need to know about.

projection(*tile: hips.tiles.tile.HipsTile*) → skimage.transform._geometric.ProjectiveTransform
Estimate projective transformation on a HiPS tile.

run() → numpy.ndarray
Draw HiPS tiles onto an empty image.

warp_image(*tile: hips.tiles.tile.HipsTile*) → numpy.ndarray
Warp a HiPS tile and a sky image.

16.2.3 HipsSurveyProperties

class hips.**HipsSurveyProperties**(*data: dict*)
Bases: object

HiPS properties container.

Parameters
data : dict

HiPS survey properties

Examples

```
>>> from hips import HipsSurveyProperties
>>> url = 'http://alasky.unistra.fr/DSS/DSS2Merged/properties'
>>> hips_survey_property = HipsSurveyProperties.fetch(url)
>>> hips_survey_property.base_url
'http://alasky.u-strasbg.fr/DSS/DSS2Merged'
```

Attributes Summary

astropy_frame	Astropy coordinate frame (str).
base_url	HiPS access URL
hips_frame	HiPS coordinate frame (str).
hips_order	HiPS order (int).
hips_service_url	HiPS service base URL (str).
hips_to_astropy_frame_mapping	HIPS to Astropy SkyCoord frame string mapping.
hips_version	HiPS version (str).
tile_format	HiPS tile format (str).
tile_width	HiPS tile width
title	HiPS title (str).

Methods Summary

fetch(url)	Read from HiPS survey description file from remote URL (HipsSurveyProperties).
from_name(name)	Create object from Survey ID (HipsSurveyProperties).
make(hips_survey, _ForwardRef()])	Convenience constructor for from_string classmethod or existing object (HipsSurveyProperties).
parse(text, url)	Parse HiPS survey description text (HipsSurveyProperties).
read(filename)	Read from HiPS survey description file (HipsSurveyProperties).
tile_url(tile_meta)	Tile URL on the server (str).
to_string()	Convert properties to string
write(path)	Write properties to text file.

Attributes Documentation

astropy_frame
Astropy coordinate frame (str).

base_url
HiPS access URL

hips_frame
HiPS coordinate frame (str).

hips_order

HiPS order (int).

hips_service_url
HiPS service base URL (str).

hips_to_astropy_frame_mapping = {'ecliptic': 'ecliptic', 'equatorial': 'icrs', 'galactic': 'galactic'}
HIPS to Astropy SkyCoord frame string mapping.

hips_version
HiPS version (str).

tile_format
HiPS tile format (str).

tile_width
HiPS tile width

title
HiPS title (str).

Methods Documentation

classmethod fetch(*url: str*) → hips.tiles.survey.HipsSurveyProperties
Read from HiPS survey description file from remote URL (HipsSurveyProperties).

Parameters
url : str

URL containing HiPS properties

classmethod from_name(*name: str*) → hips.tiles.survey.HipsSurveyProperties
Create object from Survey ID (HipsSurveyProperties).

classmethod make(*hips_survey: Union[str, _ForwardRef('HipsSurveyProperties')]*) → hips.tiles.survey.HipsSurveyProperties
Convenience constructor for from_string classmethod or existing object (HipsSurveyProperties).

classmethod parse(*text: str*, *url: str = None*) → hips.tiles.survey.HipsSurveyProperties
Parse HiPS survey description text (HipsSurveyProperties).

Parameters
text : str

Text containing HiPS survey properties

url : str

Properties URL of HiPS

classmethod read(*filename: str*) → hips.tiles.survey.HipsSurveyProperties
Read from HiPS survey description file (HipsSurveyProperties).

Parameters
filename : str

HiPS properties filename

tile_url(*tile_meta: hips.tiles.tile.HipsTileMeta*) → str
Tile URL on the server (str).

to_string()
Convert properties to string

write(*path*)
Write properties to text file.

Parameters
path : str or Path

Base path where to write the properties file.

16.2.4 HipsSurveyPropertiesList

class hips.**HipsSurveyPropertiesList**(*data: List[hips.tiles.survey.HipsSurveyProperties]*)
Bases: object

HiPS survey properties list.

Parameters
data : list

Python list of HipsSurveyProperties

Examples

Fetch the list of available HiPS surveys from CDS:

```
>>> from hips import HipsSurveyPropertiesList
>>> surveys = HipsSurveyPropertiesList.fetch()
```

Look at the results:

```
>>> len(surveys.data)
335
>>> survey = surveys.data[0]
>>> survey.title
'2MASS H (1.66 microns)'
>>> survey.hips_order
9
```

You can make a astropy.table.Table of available HiPS surveys:

```
>>> table = surveys.table
```

and then do all the operations that Astropy table supports, e.g.

```
>>> table[['ID', 'hips_order', 'hips_service_url']][[1, 30, 42]]
>>> table.show_in_browser(jsviewer=True)
>>> table.show_in_notebook()
>>> table.to_pandas()
```

Attributes Summary

DEFAULT_URL	Default URL to fetch HiPS survey list from CDS.
table	Table with HiPS survey infos (Table).

Methods Summary

fetch(url)	Fetch HiPS list text from remote location (HipsSurveyPropertiesList).
from_name(name)	Return a matching HiPS survey (HipsSurveyProperties).
parse(text)	Parse HiPS list text (HipsSurveyPropertiesList).
read(filename)	Read HiPS list from file (HipsSurveyPropertiesList).

Attributes Documentation

DEFAULT_URL = 'http://alasky.unistra.fr/MocServer/query?hips_service_url=*&dataproduct_type=!catalog&dat
Default URL to fetch HiPS survey list from CDS.

table
Table with HiPS survey infos (Table).

Methods Documentation

classmethod fetch(*url: str = None*) → hips.tiles.survey.HipsSurveyPropertiesList
Fetch HiPS list text from remote location (HipsSurveyPropertiesList).

Parameters
url : str

HiPS list URL

from_name(*name: str*) → hips.tiles.survey.HipsSurveyProperties
Return a matching HiPS survey (HipsSurveyProperties).

classmethod parse(*text: str*) → hips.tiles.survey.HipsSurveyPropertiesList
Parse HiPS list text (HipsSurveyPropertiesList).

Parameters
text : str

HiPS list text

classmethod read(*filename: str*) → hips.tiles.survey.HipsSurveyPropertiesList
Read HiPS list from file (HipsSurveyPropertiesList).

Parameters
filename : str

HiPS list filename

16.2.5 HipsTile

class hips.**HipsTile**(*meta: hips.tiles.tile.HipsTileMeta*, *raw_data: bytes*)
Bases: object

HiPS tile container.

This class provides methods for fetching, reading, and writing a HiPS tile.

Note: In HiPS, the pixel data is flipped in the y direction for `jpg` and `png` format with respect to FITS. In this package, we handle this by flipping `jpg` and `png` data to match the `fits` orientation, at the I/O boundary, i.e. in `from_numpy` and `to_numpy`.

Parameters

meta : `HipsTileMeta`

Metadata of HiPS tile

raw_data : `bytes`

Raw data (copy of bytes from file)

Examples

Fetch a HiPS tile:

```
>>> from hips import HipsTile, HipsTileMeta
>>> meta = HipsTileMeta(order=6, ipix=30889, file_format='fits')
>>> url = 'http://alasky.unistra.fr/2MASS/H/Norder6/Dir30000/Npix30889.fits'
>>> tile = HipsTile.fetch(meta, url)
```

The tile pixel data is available as a Numpy array:

```
>>> type(tile.data)
numpy.ndarray
>>> tile.data.shape
(512, 512)
>>> tile.data.dtype.name
int16
```

Attributes Summary

`children`	Create four children tiles from parent tile.
`data`	Tile pixel data (`ndarray`).

Methods Summary

`fetch`(meta, url)	Fetch HiPS tile and load into memory (`HipsTile`).
`from_numpy`(meta, data)	Create a tile from given pixel data.
`read`(meta, filename)	Read HiPS tile data from a directory and load into memory (`HipsTile`).
`to_numpy`(raw_data, fmt)	Convert raw image bytes to Numpy array pixel data.
`write`(filename)	Write to file.

Attributes Documentation

children

Create four children tiles from parent tile.

data
Tile pixel data (ndarray).

This is a cached property, it will only be computed once.

See the to_numpy function.

Methods Documentation

classmethod fetch(*meta: hips.tiles.tile.HipsTileMeta*, *url: str*) → hips.tiles.tile.HipsTile
Fetch HiPS tile and load into memory (HipsTile).

Parameters
meta : HipsTileMeta

Metadata of HiPS tile

url : str

URL containing HiPS tile

classmethod from_numpy(*meta: hips.tiles.tile.HipsTileMeta*, *data: numpy.ndarray*) → hips.tiles.tile.HipsTile
Create a tile from given pixel data.

Parameters
meta : HipsTileMeta

Metadata of HiPS tile

data : ndarray

Tile pixel data

Returns
tile : HipsTile

HiPS tile object in the format requested in meta.

classmethod read(*meta: hips.tiles.tile.HipsTileMeta*, *filename: str = None*) → hips.tiles.tile.HipsTile
Read HiPS tile data from a directory and load into memory (HipsTile).

Parameters
meta : HipsTileMeta

Metadata of HiPS tile

filename : str

Filename

static to_numpy(*raw_data: bytes*, *fmt: str*) → numpy.ndarray
Convert raw image bytes to Numpy array pixel data.

Parameters
raw_data : bytes

Raw image bytes (usually read from file or fetched from URL)

fmt : {'fits', 'jpg', 'png'}

File format

Returns
data : ndarray

Pixel data as a numpy array

write(*filename: str*) → None
Write to file.

Parameters
filename : str

Filename

16.2.6 HipsTileAllskyArray

class hips.**HipsTileAllskyArray**(*meta: hips.tiles.tile.HipsTileMeta*, *raw_data: bytes*)
Bases: hips.HipsTile

All-sky tile array container.

To quote from section 4.3.2 "Allsky preview file" of the HiPS IVOA working draft: "The tiles at low orders (0 to 3) may be packaged together into a unique file called Allsky."

This class implements that all-sky tile array format.

TODO: We're sub-classing HipsTile here at the moment. This is weird! Probably the current HipsTile should be renamed ImageIO or be split up into functions that do image I/O in the three supported formats?

TODO: We re-use the HipsTileMeta class to store order as well as other info like file_format and frame. Note that ipix doesn't make sense for an AllSkyTileArray. Maybe there's a better way to handle this without code duplication?

Examples

Load an example existing HiPS all-sky image (unfortunately one has to pass a dummy ipix value here):

```
>>> from hips import HipsTileAllskyArray, HipsTileMeta
>>> meta = HipsTileMeta(order=3, ipix=-1, file_format='jpg', frame='icrs')
>>> url = 'http://alasky.unistra.fr/Fermi/Color/Norder3/Allsky.jpg'
>>> allsky = HipsTileAllskyArray.fetch(meta, url)
```

Now you can extract tiles (e.g. for drawing):

```
>>> tile = allsky.tile(ipix=42)
>>> tile.meta
HipsTileMeta(order=3, ipix=42, file_format='jpg', frame='icrs', width=64)
```

TODO: add an example how to go the other way: combine tiles into an allsky image.

Attributes Summary

height	Image pixel height (int)
n_tiles	Number of tiles in the image (int).
n_tiles_in_row	Number of tiles per tile row (int).
tile_width	Pixel width of a single tile (int).
tiles	Split into a list of HipsTile.
width	Image pixel width (int).

Methods Summary

from_tiles(tiles)	Create all-sky image from list of tiles.
tile(ipix)	Extract one of the tiles (HipsTile)
tiles_to_allsky_array(tiles)	Combine tiles into an all-sky image.

Attributes Documentation

height
Image pixel height (int)

n_tiles
Number of tiles in the image (int).

n_tiles_in_row
Number of tiles per tile row (int).

tile_width
Pixel width of a single tile (int).

tiles
Split into a list of HipsTile.

This is called when using the all-sky image for drawing.

width
Image pixel width (int).

Methods Documentation

classmethod from_tiles(*tiles: List[hips.tiles.tile.HipsTile]*) → hips.tiles.allsky.HipsTileAllskyArray
Create all-sky image from list of tiles.

tile(*ipix: int*) → hips.tiles.tile.HipsTile
Extract one of the tiles (HipsTile)

A copy of the data by default. For drawing we could avoid the copy by passing copy=False here.

static tiles_to_allsky_array(*tiles: List[hips.tiles.tile.HipsTile]*) → numpy.ndarray
Combine tiles into an all-sky image.

16.2.7 HipsTileMeta

class hips.**HipsTileMeta**(*order: int*, *ipix: int*, *file_format: str*, *frame: str = 'icrs'*, *width: int = 512*)
Bases: object

HiPS tile metadata.

Parameters
order : int

HEALPix order

ipix : int

HEALPix pixel number

file_format : {'fits', 'jpg', 'png'}

File format

frame : {'icrs', 'galactic', 'ecliptic'}

Sky coordinate frame

width : int

Tile width (tiles always have width = height)

Examples

```
>>> from hips import HipsTileMeta
>>> tile_meta = HipsTileMeta(order=3, ipix=450, file_format='fits')
>>> tile_meta
HipsTileMeta(order=3, ipix=450, file_format='fits', frame='icrs', width=512)
>>> tile_meta.skycoord_corners
<SkyCoord (ICRS): (ra, dec) in deg
[( 264.375, -24.62431835), ( 258.75 , -30.        ),
( 264.375, -35.68533471), ( 270.   , -30.        )]>
>>> tile_meta.tile_default_url
'Norder3/Dir0/Npix450.fits'
>>> tile_meta.tile_default_path.as_posix()
'Norder3/Dir0/Npix450.fits'
```

Attributes Summary

skycoord_corners	Tile corner sky coordinates (SkyCoord).
tile_default_path	Tile relative filename path (Path).
tile_default_url	Tile relative URL (str).

Methods Summary

copy()	An independent copy.

Attributes Documentation

skycoord_corners
Tile corner sky coordinates (SkyCoord).

tile_default_path
Tile relative filename path (Path).

tile_default_url
Tile relative URL (str).

Methods Documentation

copy()
An independent copy.

16.2.8 WCSGeometry

class hips.**WCSGeometry**(*wcs: astropy.wcs.wcs.WCS*, *width: int*, *height: int*)

Bases: object

Sky image geometry: WCS and image shape.

Parameters

wcs : WCS

WCS projection object

width, height : int

Width and height of the image in pixels

Examples

To create a WCSGeometry, you can create any WCS and choose an image shape (number of pixels):

```
from astropy.wcs import WCS
from hips import WCSGeometry
wcs = WCS(naxis=2)
wcs.wcs.ctype[0] = 'GLON-AIT'
wcs.wcs.ctype[1] = 'GLAT-AIT'
wcs.wcs.crval[0] = 0
wcs.wcs.crval[1] = 0
wcs.wcs.crpix[0] = 1000
wcs.wcs.crpix[1] = 500
wcs.wcs.cdelt[0] = -0.01
wcs.wcs.cdelt[1] = 0.01
geometry =  WCSGeometry(wcs, width=2000, height=1000)
```

See also WCSGeometry.create as a simpler (but also not quite as flexible) way to generate WCS and WCSGeometry objects.

Attributes Summary

WCS_ORIGIN_DEFAULT	Default WCS transform origin, to be used in all WCS pix <-> world calls.
celestial_frame	Celestial frame for the given WCS (str).
center_pix	Image center in pixel coordinates (tuple of x, y).
center_skycoord	Image center in sky coordinates (SkyCoord).
fits_header	FITS header for the given WCS (Header).
pixel_skycoords	Grid of sky coordinates of the image pixels (SkyCoord).

Methods Summary

create(skydir, width, height, fov, . . .)	Create WCS object for given sky image parameters (WCSGeometry).

Continued on next page

Table 17 – continued from previous page

create_from_dict(params)	Create WCS object from a dictionary (WCSGeometry).
make(geometry, _ForwardRef()])	Convenience constructor for create_from_dict classmethod or existing object (WCSGeometry).
pix_to_sky(x, y)	Helper function to convert pix to sky coordinates.

Attributes Documentation

WCS_ORIGIN_DEFAULT = 0
Default WCS transform origin, to be used in all WCS pix <-> world calls.

celestial_frame
Celestial frame for the given WCS (str).

Calls wcs_to_celestial_frame.

center_pix
Image center in pixel coordinates (tuple of x, y).

center_skycoord
Image center in sky coordinates (SkyCoord).

fits_header
FITS header for the given WCS (Header).

pixel_skycoords
Grid of sky coordinates of the image pixels (SkyCoord).

Methods Documentation

classmethod create(*skydir: astropy.coordinates.sky_coordinate.SkyCoord, width: int, height: int, fov: Union[str, astropy.coordinates.angles.Angle], coordsys: str = 'icrs', projection: str = 'AIT'*) → hips.utils.wcs.WCSGeometry
Create WCS object for given sky image parameters (WCSGeometry).

Parameters

skydir : SkyCoord

Sky coordinate of the WCS reference point

width, height : int

Width and height of the image in pixels

fov : str or Angle

Field of view

coordsys : {'icrs', 'galactic'}

Coordinate system

projection : str

Projection of the WCS object. To see list of supported projections visit: http://docs.astropy.org/en/stable/wcs/#supported-projections

Examples

```
>>> from astropy.coordinates import SkyCoord
>>> from hips import WCSGeometry
>>> skycoord = SkyCoord(10, 20, unit='deg')
>>> geometry = WCSGeometry.create(
...     skydir=SkyCoord(0, 0, unit='deg', frame='galactic'),
...     width=2000, height=1000, fov='3 deg',
...     coordsys='galactic', projection='AIT',
... )
>>> geometry.wcs
Number of WCS axes: 2
CTYPE : 'GLON-AIT'  'GLAT-AIT'
CRVAL : 0.0  0.0
CRPIX : 500.0  1000.0
PC1_1 PC1_2  : 1.0  0.0
PC2_1 PC2_2  : 0.0  1.0
CDELT : -0.0015  0.0015
NAXIS : 0  0
>>> geometry.shape
Shape(width=2000, height=1000)
```

classmethod create_from_dict(*params: dict*) → hips.utils.wcs.WCSGeometry
Create WCS object from a dictionary (WCSGeometry).

The extra options are passed to the `create` class method, it can take the following parameters:

- target
- width
- height
- fov
- coordsys
- projection

For detailed description, see the `create` class method's docstring.

classmethod make(*geometry: Union[dict, _ForwardRef('WCSGeometry')]*) → hips.utils.wcs.WCSGeometry
Convenience constructor for create_from_dict classmethod or existing object (WCSGeometry).

pix_to_sky(*x*, *y*) → astropy.coordinates.sky_coordinate.SkyCoord
Helper function to convert pix to sky coordinates.

Part V

Changelog

CHAPTER 17

0.3 (unreleased)

- no changes yet

CHAPTER 18

0.2

Version 0.2 of hips was released on October 28, 2017.

- Change from using `healpy` to `astropy-healpix`. This means `hips` now works on Windows! [#109]
- Introduce asynchronous fetching of HiPS tiles [#106]
- Add progress bar support for fetching and drawing HiPS tiles [#105]
- Add reporting functionality for HipsPainter [#104]
- Fix tile splitting criterion [#101]

CHAPTER 19

0.1

This first version of the hips package was released on July 28, 2017. It contains a first implementation to fetch and draw tiles.

This is a very early release, to get some users and feedback. Note that the API will change in the coming weeks, and you can also expect new features, fixes and performance and usability enhancements.

The `hips` package started as a project developed as part of Google summer of code 2017, i.e. planning in early 2017 and coding in June 2017.

Part VI

Develop

CHAPTER 20

Hello!

Want to contribute to the `hips` package?

Great! Talk to us by filing a Github issue any time (it doesn't have to be a concrete feature request or bug report).

This package was created using the Astropy affiliated package template, and everything works pretty much as in Astropy and most affiliated packages.

We didn't write any developer docs specifically for this package yet. For now, check out the Astropy core package developer docs, or just talk to us if you have any questions.

CHAPTER 21

Install development version

Install the latest development version from https://github.com/hipspy/hips :

```
git clone https://github.com/hipspy/hips
cd hips
pip install .
```

Then run the tests with either of these commands:

```
python -m pytest -v hips
python setup.py test -V
```

To run all tests and get a coverage report:

```
python setup.py test -V --remote-data --coverage
```

To build the documentation, do:

```
python setup.py build_docs
```

CHAPTER 22

Get the hips-extra test datasets

To run tests accessing files from hips-extra repository:

```
git clone https://github.com/hipspy/hips-extra.git
```

Developers must have it cloned on their system, otherwise some test cases will be skipped. This contains tiles from different HiPS surveys which are used by the drawing module. After this, the `HIPS_EXTRA` environment variable must be set up on their system. On UNIX operating systems, this can be set using

```
export HIPS_EXTRA=path/to/hips-extra
```

CHAPTER 23

Why only Python 3?

This package requires Python 3.6 or later.

It will not work with Python 2.7 or 3.5!

This was a choice we made when starting this package in summer of 2017, at a time when Jupyter had just made their Python 3 only release and other packages we depend on (like Astropy) were about to drop support for legacy Python (Python 2).

Supporting only Python 3 means we e.g. get these benefits:

- async / await for asynchronous HiPS tile fetching (introduced in Python 3.5)
- Keyword-only arguments (introduced in Python 3.0)
- Type annotations (some only introduced in Python 3.6)
- f-strings (introduced in Python 3.6)

At the moment, the only Python 3.6 only feature we use are f-strings, so if several potential users that are on Python 3.5 and can't easily upgrade for some reason complain, we might consider supporting Python 3.5 in the next release.

Part VII

HiPS tile drawing

This section describes the HiPS tile drawing algorithm implemented in this package, to create a sky image for a given WCS.

The original description was for the algorithm implemented in Aladin Lite, written by Thomas Boch. In the meantime, the algorithm implemented in this Python package has deviated a bit, they are no longer the same.

The implementation is based on `numpy`, `astropy`, `healpy` and `scikit-image`.

CHAPTER 24

Naive algorithm

This is a naive (one could also say: simple and fast) algorithm for drawing HiPS tiles using affine transformations, implemented in the `HipsPainter` class and usually executed by users via the high-level `make_sky_image` function.

First we compute and fetch the tiles that are needed for the given sky image:

1. The user specifies a `WCSGeometry`, which is a `astropy.wcs.WCS` as well as a width and height of the sky image to compute.
2. Compute HiPS order corresponding to the requested image size/resolution. The attributes of HiPS properties needed for this are `hips_order` (order at the tile level) and `hips_tile_width` (number of pixels for tile width and height). If hips_tile_width is missing, a default value of 512 is assumed.
3. Compute the list of tiles corresponding to the image FoV. This is done by computing the HiPS tile HEALPix pixel index for every pixel in the sky image and then computing the unique set.
4. Fetch (HTTP calls or from a local cache) all tiles in the list.

Then we draw the tiles one by one using these steps:

1. For each tile, compute the world coordinates of the tile corner vertices, using healpy `boundaries` function.
2. For each tile, project vertices in image coordinates according to the requested WCS (performing ICRS to Galactic frame transformation if the HiPS and sky image aren't in the same frame already).
3. We extend the tile by 1 pixel in all directions in order to hide "stitches" with other tiles drawing (TODO: not done yet. needed?)
4. The four corners uniquely define a projective transform between pixel coordinates on the tile and the output sky image. We use scikit-image to compute and apply that transform, which uses cubic spline interpolation under the hood. Thus the output is always float data, even if the input was integer RGB image data.

At the moment, we simply initialise the output sky image with pixel values of zero, and then sum the sky images we get from each projected tile. This is inefficient, and can result in incorrect pixel values at the lines corresponding to tile borders. We plan to implement a better (more efficient and more correct) way to handle that soon.

Note that any algorithm using interpolation is not fully conserving flux or counts. This might be a concern if you use the resulting sky images for data analysis. It's your responsibility to decide if using this method is appropriate for your application or not!

CHAPTER 25

Tile distortion issue

While the algorithm previously described works fine for HiPS tiles not distorted, it brings some astrometry offsets for distorted tiles. This distortion is strongly visible in the HEALPix scheme for tiles at the boundary between the equatorial zone and the polar cap.

An example of such distortions is shown in the example below (uncheck *Activate deformations reduction algorithm* to view the astrometry offsets): http://cds.unistra.fr/~boch/AL/test-reduce-deformations2.html

To overcome this problem, Aladin Desktop and Aladin Lite use the following recursive strategy: for tiles either too large (one edge is >300 pixels when projected) or too distorted (ratio of smaller diagonal on larger diagonal is smaller than 0.7 and one of the diagonal is > 150 pixels when projected):

- We consider 4 children tiles, dynamically generated from the pixels of their father. Each children tile has a width and height equal to half of its father's width/height.
- For each children tile, we compute the world coordinates of its vertices, project them and either draw it if not too distorted or repeat the process by splitting again into 4 children tiles.

The recursion is limited by a maximum number of recursive steps (for 512x512 tiles, you are limited to a maximum of 9 steps as 2^9=512) and/or a maximum order (maximum order set arbitrarily at 19 in Aladin Desktop).

CHAPTER 26

Precise algorithm

Note: The precise algorithm isn't implemented yet.

Contrary the previous algorithm which used affine transformations, the idea here for the drawing step is to scan the result image pixels, and for each of them interpolate (Nearest neighbour or bilinear) the value, ie compute the indexes of nearest neighbour(s), retrieve the values of these pixels and merge them to determine the value of the target pixel. This is very similar to what reproject is doing.

One challenge is that one needs to know how to find the tile and pixel corresponding to a given HEALPix index. The correspondance between a HEALPix index and a pixel in a HiPS tile is given by a `hpx2xy` array (see method `createHpx2xy` in class `cds.tools.pixtools.Util` from Aladin Desktop source code.)

CHAPTER 27

WCS for FITS tiles

It seems that the astrometry of a HiPS tile can be accurately described using a WCS header like this one (example for HiPS in equatorial frame, Norder 3, Npix 448):

```
NAXIS   =                    2 / number of data axes
NAXIS1  =                  512 / length of data axis 1
NAXIS2  =                  512 / length of data axis 1
CRPIX1  =              -2047.5 / Coordinate reference pixel
CRPIX2  =              -5631.5 / Coordinate reference pixel
CD1_1   = -1.0986328125000E-02 / Transformation matrix (rot + scale)
CD1_2   = -1.0986328125000E-02 / Transformation matrix (rot + scale)
CD2_1   =  1.0986328125000E-02 / Transformation matrix (rot + scale)
CD2_2   = -1.0986328125000E-02 / Transformation matrix (rot + scale)
CTYPE1  = 'RA---HPX'            / Longitude in an HPX projection
CTYPE2  = 'DEC--HPX'            /  Latitude in an HPX projection
CRVAL1  =                   0. / [deg] Longitude at the reference point
CRVAL2  =                   0. / [deg]  Latitude at the reference point
PV2_1   =                   4 / HPX H parameter (longitude)
PV2_2   =                   3 / HPX K parameter  (latitude)
```

HPX projection is supported by WCSLib. It is understood by DS9. Support in other tools (reproject, Montage, etc) is unclear and has to be tested.

Note: It seems that we can define a WCS for each tile. If so, this would allow us to simply use the `reproject` package to draw the tiles, which would be an alternative "precise" algorithm.

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