
healsparse

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HealSparse is a sparse implementation of [HEALPix](#) in Python, written for the Rubin Observatory Legacy Survey of Space and Time Dark Energy Science Collaboration ([DESC](#)). *HealSparse* is a pure Python library that sits on top of [numpy](#) and [healpy](#) and is designed to avoid storing full sky maps in case of partial coverage, including easy reading of sub-maps. This reduces the overall memory footprint allowing maps to be rendered at arcsecond resolution while keeping the familiarity and power of [healpy](#).

HealSparse expands on [healpy](#) and straight [HEALPix](#) maps by allowing maps of different data types, including 32- and 64-bit floats; 8-, 16-, 32-, and 64-bit integers; “wide bit masks” of arbitrary width (allowing hundreds of bits to be efficiently and conveniently stored); and [numpy](#) record arrays. Arithmetic operations between maps are supported, including sum, product, min/max, and and/or/xor bitwise operations for integer maps. In addition, there is general support for any [numpy](#) universal function.

HealSparse also includes a simple geometric primitive library, to render circles and convex polygons.

The code is hosted in [GitHub](#). Please use the [issue tracker](#) to let us know about any problems or questions with the code.

INSTALL

HealSparse requires [healpy](#), [numpy](#), and [astropy](#). If you have [fitsio](#) installed then additional features including memory-efficient concatenation of *HealSparse* maps are made available.

HealSparse is available at [pypi](#), and the most convenient way of installing the latest released version is simply:

```
pip install healsparse
```

To install from source, you can run from the root directory:

```
python setup.py install
```

or use *pip* from the root directory:

```
pip install .
```


QUICKSTART

A [jupyter notebook](#) is available for tutorial purposes [here](#)

BASIC HEALSPARSE INTERFACE

3.1 Getting Started

To conserve memory, *HealSparse* uses a dual-map approach, where a low-resolution full-sky “coverage map” is combined with a high resolution map containing the pixel data where it is available. The resolution of the coverage map is controlled by the `nside_coverage` parameter, and the resolution of the high-resolution map is controlled by the `nside_sparse` parameter. Behind the scenes, *HealSparse* uses clever indexing to allow the user to treat these as contiguous maps with minimal overhead. **All HealSparse maps use HEALPix nest indexing behind the scenes, should be treated as nest-indexed maps.**

There are 3 basic ways to make a `HealSparseMap`. First, one can read in an existing *HEALPix* map; second, one can read in an existing `HealSparseMap`; and third, one can create a new map.

```
import numpy as np
import healsparse

# To read a HEALPix map, the nside_coverage must be specified
map1 = healsparse.HealSparseMap.read('healpix_map.fits', nside_coverage=32)

# To read a healsparse map, no additional keywords are necessary
map2 = healsparse.HealSparseMap.read('healsparse_map.hs')

# To read part of a healsparse map, you can specify the coverage pixels to read
map2_partial = healsparse.HealSparseMap.read('healsparse_map.hs', pixels=[100, 101])

# To create a new map, the resolutions and datatype must be specified
nside_coverage = 32
nside_sparse = 4096
map3 = healsparse.HealSparseMap.make_empty(nside_coverage, nside_sparse, np.float64)
```

To set values in the map, you can use simple indexing or the explicit API:

```
map3[0: 1000] = np.arange(1000, dtype=np.float64)
map3.update_values_pix(np.arange(1000, 2000), np.arange(1000, dtype=np.float64), ↵
↵ nest=True)
```

To retrieve values from the map, you can use simple indexing or the explicit API via pixels or positions:

```
print(map3[0: 1000])
>>> [0. ... 999.]
print(map3.get_values_pix(np.arange(1000, 2000), nest=True))
>>> [0. ... 999.]
print(map3.get_values_pos(45.0, 0.1, lonlat=True))
>>> 51.0
```

A `HealSparseMap` has the concept of “valid pixels”, the pixels over which the map is defined (as opposed to `healpy.UNSEEN` in the case of floating point maps). You can retrieve the array of valid pixels or the associated positions of the valid pixels easily:

```
print(map3.valid_pixels)
>>> [ 0    1    2 ... 1997 1998 1999]

ra, dec = map3.valid_pixels_pos(lonlat=True)
print(ra)
>>> [45.         ... 45.3515625 ]
print(dec)
>>> [0.00932548 ... 0.81134431]
```

You can convert a `HealSparseMap` to a `healpy` map (numpy array) either by using a full slice (`[:]`) or with the `generate_healpix_map()` method. Do watch out, at high resolution this can blow away your memory! In these cases, `generate_healpix_map()` can degrade the map before conversion, using a reduction function (over valid pixels) of your choosing, including mean, median, std, max, or min.

```
hmap4096 = map3[: ]
hmap128 = map3.generate_healpix_map(nside=128, reduction='mean')
```

3.2 Integer Maps

In addition to floating-point maps, which are natively supported by `healpy`, `HealSparseMap` supports integer maps. The “sentinel” value of these maps (equivalent to `healpy.UNSEEN`) is either `-MAXINT` or `0`, depending on the desired use of the map (e.g., integer values or positive bitmasks). Note that these maps cannot be trivially converted to `healpy` maps because *HEALPix* has no concept of sentinel values that are not `healpy.UNSEEN`, which is a very large negative floating-point value.

```
import numpy as np
import healsparse

map_int = healsparse.HealSparseMap.make_empty(32, 4096, np.int32)
print(map_int)
>>> HealSparseMap: nside_coverage = 32, nside_sparse = 4096, int32

map_int[0: 1000] = np.arange(1000, dtype=np.int32)

print(map_int[500])
>>> 500
```

3.3 Recarray Maps

`HealSparseMap` also supports maps made up of `numpy` record arrays. These recarray maps will have one field that is the “primary” field which is used to test if a pixel has a valid value or not. Therefore, these recarray maps should be used to describe associated values that share the exact same valid footprint. Each field in the recarray can be treated as its own `HealSparseMap`. For example,

```
import numpy as np
import healsparse

dtype = [('a', np.float32), ('b', np.int32)]
```

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```

map_rec = healsparse.HealSparseMap.make_empty(32, 4096, dtype, primary='a')

map_rec[0: 10000] = np.zeros(10000, dtype=dtype)
print(map_rec.valid_pixels)
>>> [ 0  1  2 ... 9997 9998 9999]

map_rec['a'][0: 5000] = np.arange(5000, dtype=np.float32)
map_rec['b'][5000: 10000] = np.arange(5000, dtype=np.int32)

print(map_rec[map_rec.valid_pixels])
>>> [(0., 0) (1., 0) (2., 0) ... (0., 4997) (0., 4998) (0., 4999)]

```

Note that the call `map_rec['a'][0: 5000] = values` will work, but `map_rec[0: 5000]['a'] = values` will not. Also note that using the fields of the recarray *cannot* be used to set new pixels, this construction can only be used to change pixel values.

3.4 Wide Masks

HealSparse has support for “wide” bit masks with an arbitrary number of bits that are referred to by bit position rather than value. This is useful, for example, when constructing a coadd coverage map where every pixel can uniquely identify the set of input exposures that contributed at the location of that pixel. In the case of >64 input exposures you can no longer use a simple 64-bit integer bit mask. Wide mask bits are always specified by giving a list of integer positions rather than values (e.g., use 10 to set the 10th bit instead of $1024 = 2^{10}$).

```

import numpy as np
import healsparse

map_wide = healsparse.HealSparseMap.make_empty(32, 4096, healsparse.WIDE_MASK, wide_
↳mask_maxbits=128)

pixels = np.arange(10000)
map_wide.set_bits_pix(pixels, [4, 100])

print(map_wide.check_bits_pix(pixels, [2]))
>>> [False False False ... False False False]
print(map_wide.check_bits_pix(pixels, [4]))
>>> [ True  True  True ...  True  True  True]
print(map_wide.check_bits_pix(pixels, [100]))
>>> [ True  True  True ...  True  True  True]
print(map_wide.check_bits_pix(pixels, [101]))
>>> [False False False ... False False False]

# Check if any of the bits are set
print(map_wide.check_bits_pos([45.2], [0.2], [100, 101], lonlat=True))
>>> [ True]

```

3.5 Writing Maps

Writing a HealSparseMap is easy:

```
map3.write('output_file.hs', clobber=False)
```

3.6 Metadata

You can also set key/value metadata to a map that will be stored in the fits header of the file and read back in. The keys must conform to FITS header key standards (strings, upper case). The metadata will be stored as a Python dictionary, and can be accessed with the `metadata` property.

```
metadata = {'KEY1': 5, 'KEY2': 10.0}
map3.metadata = metadata
print(map3.metadata['KEY2'])
>>> 10.0
```

3.7 Coverage Masks

A HealSparseMap contains a coverage map that defines the coarse coverage over the sky. You can retrieve a boolean array describing which pixels are covered in the map with the `coverage_mask` property:

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

cov_mask = map3.coverage_mask
cov_pixels, = np.where(cov_mask)
ra, dec = hp.pix2ang(map3.nside_coverage, cov_pixels, lonlat=True, nest=True)
plt.plot(ra, dec, 'r.')
plt.show()
```

It is also possible to read the coverage map of a HealSparseMap on its own:

```
cov_map = healsparse.HealSparseCoverage.read('output_file.hs')
cov_mask = cov_map.coverage_mask
```

HEALSPARSE MAP OPERATIONS

4.1 Introduction

HealSparse has support for basic arithmetic operations between maps, including sum, product, min/max, and and/or/xor bitwise operations for integer maps. In addition, there is general support for any `numpy` universal function. It is important to note that map operations are complicated by the fact that any given maps may not have the same pixel coverage. Therefore, map operations can be done either with “union” (where the final map has a valid pixel list that is the union of the input maps) or “intersection” (where the final map has a valid pixel list that is the intersection of the input maps). In the case of “union” operations, the maps that do not have coverage at a given point will be filled with an appropriate value (for example, 0 for summation and 1 for products).

4.2 Operations With a Constant

Arithmetic operations with a constant are very simple, and are handled with the default Python operations, supporting copy or in-place operations.

```
import numpy as np
import healsparse

map_float = healsparse.HealSparseMap.make_empty(32, 4096, np.float64)
map_float[0: 10000] = np.zeros(1, dtype=np.float64)

print(map_float[0: 10000])
>>> [0. 0. 0. ... 0. 0. 0.]

map_float += 10.0
print(map_float[0: 10000])
>>> [10. 10. 10. ... 10. 10. 10.]

map_float /= 10.0
print(map_float[0: 10000])
>>> [1. 1. 1. ... 1. 1. 1.]

map_float2 = map_float*100.0
print(map_float[0: 10000])
>>> [1. 1. 1. ... 1. 1. 1.]
print(map_float2[0: 10000])
>>> [100. 100. 100. ... 100. 100. 100.]
```

4.3 Operations With Multiple Maps

Operations between maps can be done with either “union” or “intersection” mode. The basic operations supported are sum, product, min, max, or, and, xor, and ufunc. Note that or, and, and xor operations are only supported for integer maps. Note that operations between maps are only supported if they have the same `nside_sparse` resolution and data type. In all cases, the function name is `operation_union()` or `operation_intersection()`. For example,

```
import numpy as np
import healsparse

map1 = healsparse.HealSparseMap.make_empty(32, 4096, np.float64)
map1[0: 10000] = np.ones(10000)
map2 = healsparse.HealSparseMap.make_empty_like(map1)
map2[5000: 15000] = np.ones(10000)*5.0

# The union sum will have coverage that was from map1 OR map2
sum_union = healsparse.operations.sum_union([map1, map2])
print(sum_union[sum_union.valid_pixels].min())
>>> 1.0
print(sum_union[sum_union.valid_pixels].max())
>>> 6.0
print(sum_union[sum_union.valid_pixels].min(), sum_union[sum_union.valid_pixels].max())
>>> 0 14999

# The intersection sum will have coverage that was from map1 AND map2
sum_intersection = healsparse.operations.sum_intersection([map1, map2])
print(sum_intersection[sum_intersection.valid_pixels].min())
>>> 6.0
print(sum_intersection[sum_intersection.valid_pixels].max())
>>> 6.0
print(sum_intersection[sum_intersection.valid_pixels].min(), sum_intersection[sum_intersection.valid_pixels].max())
>>> 5000 9999
```


HEALSPARSE GEOMETRY

HealSparse has a basic geometry library that allows you to generate maps from circles and convex polygons, as supported by `healpy`. Each geometric object is associated with a single value. On construction, geometry objects only contain information about the shape, and they are only rendered onto a *HEALPix* grid when requested.

There are two methods to realize geometry objects. The first is that each object can be used to generate a `HealSparseMap` map, and the second, for integer-valued objects is the `realize_geom()` method which can be used to combine multiple objects by `or`-ing the integer values together.

5.1 HealSparse Geometry Shapes

The two shapes supported are `Circle` and `Polygon`. They share a base class, and while the instantiation is different, the operations are the same.

Circle

```
import healsparse

# All units are decimal degrees
circ = healsparse.Circle(ra=200.0, dec=0.0, radius=1.0, value=1)
```

Convext Polygon

```
# All units are decimal degrees
poly = healsparse.Polygon(ra=[200.0, 200.2, 200.3, 200.2, 200.1],
                          dec=[0.0, 0.1, 0.2, 0.25, 0.13],
                          value=8)
```

5.2 Making a Map

To make a map from a geometry object, use the `get_map()` method as such. The higher resolution you choose, the better the aliasing at the edges (given that these are pixelized approximations of the true shapes). You can also combine two maps using the general operations. Note that if the polygon is an integer value, the default sentinel when using `get_map()` is 0.

```
smap_poly = poly.get_map(nside_coverage=32, nside_sparse=32768, dtype=np.int16)
smap_circ = circ.get_map(nside_coverage=32, nside_sparse=32768, dtype=np.int16)

combo = healsparse.or_union([smap_poly, smap_circ])
```

5.3 Using `realize_geom()`

You can only use `realize_geom()` to create maps from combinations of polygons if you are using integer maps, and want to `or` them together. This method is more memory efficient than generating each individual individual map and combining them, as above.

```
realized_combo = healsparse.HealSparseMap.make_empty(32, 32768, np.int16, sentinel=0)
healsparse.realize_geom([poly, circ], realized_combo)
```

CONCATENATION OF HEALSPARSE FILES

HealSparse contains a routine for concatenating (combining) multiple HealSparseMap files. If `fitsio` is available, this will be done in a memory-efficient way. In this way, multiple non-overlapping maps can be combined. This makes possible a simple parallelized scatter-gather approach to creating complex survey maps, where individual tiles are run independently, and then all combined at the end.

6.1 Using `cat_healsparse_files()`

The `cat_healsparse_files()` routine takes in a list of filename, and an output filename. The individual files must have the same `nside_sparse`, but may have different `nside_coverage`. The output file will have the same `nside_coverage` as the first input file unless otherwise specified.

By default, for speed, the code will not check that the input HealSparseMap files are non-overlapping (that is, that they do not share `valid_pixels`; they may share coverage in the coverage map). This can be checked.

If `fitsio` is available (recommended), the combination is not done in-memory. This behavior can be modified by the user by setting `in_memory` to `True`. However, if only `astropy.io.fits` is available for FITS interfacing, the concatenation can only be done in-memory (and the `in_memory` value should be overridden).

```
import healsparse

healsparse.cat_healsparse_files(file_list, outfile, check_overlap=False,
                                ↪clobber=False,
                                in_memory=False, nside_coverage_out=None)
```


HEALSPARSEMAP FILE SPECIFICATION V1.1.2

A HealSparseMap file is a standard FITS file with two extensions. The primary (zeroth) extension is an integer image that describes the coverage map, and the first extension is an image or binary table that describes the sparse map. This document describes the file format specification of these two extensions in the FITS file.

7.1 Terminology

This is a list of terminology used in a HealSparseMap file:

- `nside_sparse`: The *HEALPix* `nside` for the fine-grained (sparse) map
- `nside_coverage`: The *HEALPix* `nside` for the coverage map
- `bit_shift`: The number of bits to shift to convert from `nside_sparse` to `nside_coverage` in the *HEALPix* NEST scheme. $\text{bit_shift} = 2 * \log_2(\text{nside_sparse} / \text{nside_coverage})$.
- `valid_pixels`: The list of pixels with defined values ($> \text{sentinel}$) in the sparse map.
- `sentinel`: The sentinel value that notes if a pixel is not a valid pixel. Default is `healpy.UNSEEN` for floating-point maps, `-MAXINT` for integer maps, and 0 for wide mask maps.
- `nfine_per_cov`: The number of fine (sparse) pixels per coverage pixel. $\text{nfine_per_cov} = 2^{*\text{bit_shift}}$.
- `wide_mask_width`: The width of a wide mask, in bytes.

7.2 Pixel Lookups

The HealSparseMap file format is derived from the method of encoding fast look-ups of arbitrary pixel values using the *HEALPix* nest pixel scheme.

Given a nest-encoded sparse (high resolution) pixel value, `pix_nest`, we can compute the coverage (low resolution) pixel value with a simple bit shift operation: `ipnest_cov = right_shift(pix_nest, bit_shift)`, where `bit_shift` is defined in [Terminology](#).

The sparse map itself is stored in blocks of data, each of which includes `nfine_per_cov` contiguous pixels for each coverage pixel that contains valid data. To find the location *within* a given a coverage block, we need to subtract the first fine (sparse) nest pixel value for the given coverage pixel. Therefore, `first_pixel = nfine_per_cov * ipnest_cov`.

Next, if we have a map of offsets which points to the location of the proper sparse map block, `cov_map_raw_offset`, we find the look-up index is `index = pix_nest -`

$\text{nfine_per_cov} * \text{ipnest_cov} + \text{cov_map_raw_offset}[\text{ipnest_cov}]$. In practice, we can combine the final terms here. The look-up index is then $\text{index} = \text{pix_nest} + \text{cov_map}[\text{ipnest_cov}]$ where $\text{cov_map} = \text{cov_map_raw_offset}[\text{ipnest_cov}] - \text{nfine_per_cov} * \text{ipnest_cov}$.

As described in *Sparse Map*, the first block in the sparse map is special, and is always filled with sentinel values. All `cov_map` indices for coverage pixels outside the coverage map point to this sentinel block.

7.3 Coverage Map

The coverage map encodes the mapping from raw pixel number to location within the sparse map. It is an integer (`numpy.int64`) map with $12 * \text{nside_coverage} * \text{nside_coverage}$ values, all of which are filled. The structure of the coverage map is as follows.

Coverage Map Header

The coverage map header must contain the following keywords:

- **EXTNAME** must be "COV"
- **PIXTYPE** must be "HEALSPARSE"
- **NSIDE** is equal to `nside_coverage`

Coverage Map Image

As described in *Pixel Lookups*, the coverage map image contains indices that are offset pointers to the block in the sparse map with associated values for that coverage pixel. An empty `HealSparseMap` is initialized with the following coverage pixel values, which all point to the first `sentinel` block in the sparse map.

```
import numpy as np
import healpy as hp

cov_map[:] = -1 * np.arange(hp.nside2npix(nside_coverage), dtype=np.int64) * nfine_per_cov
```

7.4 Sparse Map

The sparse map contains the map data, split into blocks, each of which is `nfine_per_cov` elements long. The first block is special, and is always filled with `sentinel` values.

The following datatypes are allowed:

- 1-byte unsigned integer (`numpy.uint8`)
- 1-byte signed integer (`numpy.int8`)
- 2-byte unsigned integer (`numpy.uint16`)
- 2-byte signed integer (`numpy.int16`)
- 4-byte unsigned integer (`numpy.uint32`)
- 4-byte signed integer (`numpy.int32`)
- 8-byte signed integer (`numpy.int64`)
- 4-byte floating point (`numpy.float32`)
- 8-byte floating point (`numpy.float64`)
- Numpy record array of numeric types that can be serialized with FITS

- The `WIDE_MASK` special encoding

Sparse Map Header

The sparse map header must contain:

- **EXTNAME** must be `"SPARSE"`
- **PIXTYPE** must be `"HEALSPARSE"`
- **SENTINEL** is equal to `sentinel`

If the sparse map is a numpy record array, it must contain:

- **PRIMARY** is equal to the name of the “primary” field which defines the valid pixels.

If the sparse map is a wide mask, it must contain:

- **WIDEMASK** must be `True`
- **WWIDTH** must be the width (in bytes) of the wide mask.

Sparse Map Image

If the sparse map is not of a numpy record array type, it is stored as a one dimensional image array. The first block of `nfine_per_cov` values are set to `sentinel`. Each additional block of `nfine_per_cov` is associated with a single element in the coverage map. These blocks may be in any arbitrary order, allowing for easy appending of new coverage pixels. All invalid pixels must be set to `sentinel`.

Sparse Map Wide Mask

If the sparse map is a wide mask map, the sparse map is stored as a flattened version of the in-memory `wide_mask_width * npix` array. This should be flattened on storage, and reshaped on read, using the default numpy memory ordering. The sentinel value for wide masks must be 0, and all invalid pixels must be set to 0.

Sparse Map Table

If the sparse map is a numpy record array type, it is stored as a one dimensional table array. The first block of `nfine_per_cov` values are set such that the `primary` field must be set to `sentinel`. As with the sparse map image, each additional block of `nfine_per_cov` is associated with a single element in the coverage map. These blocks may be in any arbitrary order, allowing for easy appending of new coverage pixels. All invalid pixels must have the `primary` field set to `sentinel`.

MODULES API REFERENCE

8.1 healsparse modules

8.1.1 HealSparseMap

class healsparse.healSparseMap.**HealSparseMap** (*cov_map=None, cov_index_map=None, sparse_map=None, nside_sparse=None, healpix_map=None, nside_coverage=None, primary=None, sentinel=None, nest=True, metadata=None, _is_view=False*)

Bases: object

Class to define a HealSparseMap

__add__ (*other*)

Add a constant.

Cannot be used with recarray maps.

__and__ (*other*)

Perform a bitwise and with a constant.

Cannot be used with recarray maps.

__getitem__ (*key*)

Get part of a healpix map.

__iadd__ (*other*)

Add a constant, in place.

Cannot be used with recarray maps.

__iand__ (*other*)

Perform a bitwise and with a constant, in place.

Cannot be used with recarray maps.

__imul__ (*other*)

Multiply a constant, in place.

Cannot be used with recarray maps.

__init__ (*cov_map=None, cov_index_map=None, sparse_map=None, nside_sparse=None, healpix_map=None, nside_coverage=None, primary=None, sentinel=None, nest=True, metadata=None, _is_view=False*)

Instantiate a HealSparseMap.

Can be created with `cov_index_map`, `sparse_map`, and `nside_sparse`; or with `healpix_map`, `nside_coverage`. Also see `HealSparseMap.read()`, `HealSparseMap.make_empty()`, `HealSparseMap.make_empty_like()`.

Parameters

- **cov_map** (*HealSparseCoverage*, optional) – Coverage map object
- **cov_index_map** (*np.ndarray*, optional) – Coverage index map, will be deprecated
- **sparse_map** (*np.ndarray*, optional) – Sparse map
- **nside_sparse** (*int*, optional) – Healpix nside for sparse map
- **healpix_map** (*np.ndarray*, optional) – Input healpix map to convert to a sparse map
- **nside_coverage** (*int*, optional) – Healpix nside for coverage map
- **primary** (*str*, optional) – Primary key for recarray, required if dtype has fields.
- **sentinel** (*int* or *float*, optional) – Sentinel value. Default is *hp.UNSEEN* for floating-point types, and minimum int for int types.
- **nest** (*bool*, optional) – If input healpix map is in nest format. Default is True.
- **metadata** (*dict*-like, optional) – Map metadata that can be stored in FITS header format.
- **_is_view** (*bool*, optional) – This healSparse map is a view into another healsparse map. Not all features will be available. (Internal usage)

Returns healSparseMap

Return type *HealSparseMap*

__ior__ (*other*)

Perform a bitwise or with a constant, in place.

Cannot be used with recarray maps.

__ipow__ (*other*)

Divide a constant, in place.

Cannot be used with recarray maps.

__isub__ (*other*)

Subtract a constant, in place.

Cannot be used with recarray maps.

__itruediv__ (*other*)

Divide a constant, in place.

Cannot be used with recarray maps.

__ixor__ (*other*)

Perform a bitwise xor with a constant, in place.

Cannot be used with recarray maps.

__mul__ (*other*)

Multiply a constant.

Cannot be used with recarray maps.

__or__ (*other*)

Perform a bitwise or with a constant.

Cannot be used with recarray maps.

__pow__ (*other*)
 Raise the map to a power.
 Cannot be used with recarray maps.

__repr__ ()
 Return repr(self).

__setitem__ (*key, value*)
 Set part of a healpix map

__str__ ()
 Return str(self).

__sub__ (*other*)
 Subtract a constant.
 Cannot be used with recarray maps.

__truediv__ (*other*)
 Divide a constant.
 Cannot be used with recarray maps.

__weakref__
 list of weak references to the object (if defined)

__xor__ (*other*)
 Perform a bitwise xor with a constant.
 Cannot be used with recarray maps.

apply_mask (*mask_map, mask_bits=None, mask_bit_arr=None, in_place=True*)
 Apply an integer mask to the map. All pixels in the integer mask that have any bits in mask_bits set will be zeroed in the output map. The default is that this operation will be done in place, but it may be set to return a copy with a masked map.

Parameters

- **mask_map** (*HealSparseMap*) – Integer mask to apply to the map.
- **mask_bits** (*int*, optional) – Bits to be treated as bad in the mask_map. Default is None (all non-zero pixels are masked)
- **mask_bit_arr** (*list* or *np.ndarray*, optional) – Array of bit values, used if mask_map is a wide_mask_map.
- **in_place** (*bool*, optional) – Apply operation in place. Default is True

Returns **masked_map** – self if in_place is True, a new copy otherwise

Return type *HealSparseMap*

check_bits_pix (*pixels, bits, nest=True*)
 Check the bits at the map for a set of pixels.

Parameters

- **pixel** (*np.ndarray*) – Integer array of healpix pixels.
- **nest** (*bool*, optional) – Are the pixels in nest scheme? Default is True.
- **bits** (*list*) – List of bits to check

Returns **bit_flags** – Array of *np.bool* flags on whether any of the input bits were set

Return type *np.ndarray*

check_bits_pos (*theta_or_ra*, *phi_or_dec*, *bits*, *lonlat=False*)

Check the bits at the map for an array of positions. Positions may be theta/phi co-latitude and longitude in radians, or longitude and latitude in degrees.

Parameters

- **theta_or_ra** (*float*, array-like) – Angular coordinates of points on a sphere.
- **phi_or_dec** (*float*, array-like) – Angular coordinates of points on a sphere.
- **lonlat** (*bool*, optional) – If True, input angles are longitude and latitude in degrees. Otherwise, they are co-latitude and longitude in radians.
- **bits** (*list*) – List of bits to check

Returns **bit_flags** – Array of *np.bool* flags on whether any of the input bits were set

Return type *np.ndarray*

clear_bits_pix (*pixels*, *bits*, *nest=True*)

Clear bits of a *wide_mask* map.

Parameters

- **pixels** (*np.ndarray*) – Integer array of *sparse_map* pixel values
- **bits** (*list*) – List of bits to clear

static convert_healpix_map (*healpix_map*, *nside_coverage*, *nest=True*, *sentinel=-1.6375e+30*)

Convert a healpix map to a *healsparsemap*.

Parameters

- **healpix_map** (*np.ndarray*) – Numpy array that describes a healpix map.
- **nside_coverage** (*int*) – Nside for the coverage map to construct
- **nest** (*bool*, optional) – Is the input map in nest format? Default is True.
- **sentinel** (*float*, optional) – Sentinel value for null values in the *sparse_map*. Default is *hp.UNSEEN*

Returns

- **cov_map** (*HealSparseCoverage*) – Coverage map with pixel indices
- **sparse_map** (*np.ndarray*) – Sparse map of input values.

property coverage_map

Get the fractional area covered by the sparse map in the resolution of the coverage map

Returns **cov_map** – Float array of fractional coverage of each pixel

Return type *np.ndarray*

property coverage_mask

Get the boolean mask of the coverage map.

Returns **cov_mask** – Boolean array of coverage mask.

Return type *np.ndarray*

degrade (*nside_out*, *reduction='mean'*)

Reduce the resolution, i.e., increase the pixel size of a given sparse map.

Parameters

- **nside_out** (*int*) – Output Nside resolution parameter.

- **reduction** (*str*) – Reduction method (mean, median, std, max, min).

Returns **healSparseMap** – New map, at the desired resolution.

Return type *HealSparseMap*

property dtype

get the dtype of the map

generate_healpix_map (*nside=None, reduction='mean', key=None*)

Generate the associated healpix map

if nside is specified, then reduce to that nside

Parameters

- **nside** (*int*) – Output nside resolution parameter (should be a multiple of 2). If not specified the output resolution will be equal to the parent's sparsemap nside_sparse
- **reduction** (*str*) – If a change in resolution is requested, this controls the method to reduce the map computing the mean, median, std, max or min of the neighboring pixels to compute the “degraded” map.
- **key** (*str*) – If the parent HealSparseMap contains recarrays, key selects the field that will be transformed into a HEALPix map.

Returns **hp_map** – Output HEALPix map with the requested resolution.

Return type *np.ndarray*

get_single (*key, sentinel=None, copy=False*)

Get a single healpix map out of a recarray map, with the ability to override a sentinel value.

Parameters

- **key** (*str*) – Field for the recarray
- **sentinel** (*int* or *float* or *None*, optional) – Override the default sentinel value. Default is *None* (use default)

get_values_pix (*pixels, nest=True, valid_mask=False*)

Get the map value for a set of pixels.

Parameters

- **pixel** (*np.ndarray*) – Integer array of healpix pixels.
- **nest** (*bool*, optional) – Are the pixels in nest scheme? Default is *True*.
- **valid_mask** (*bool*, optional) – Return mask of *True/False* instead of values

Returns **values** – Array of values/validity from the map.

Return type *np.ndarray*

get_values_pos (*theta_or_ra, phi_or_dec, lonlat=False, valid_mask=False*)

Get the map value for the position. Positions may be theta/phi co-latitude and longitude in radians, or longitude and latitude in degrees.

Parameters

- **theta_or_ra** (*float*, array-like) – Angular coordinates of points on a sphere.
- **phi_or_dec** (*float*, array-like) – Angular coordinates of points on a sphere.
- **lonlat** (*bool*, optional) – If *True*, input angles are longitude and latitude in degrees. Otherwise, they are co-latitude and longitude in radians.

- **valid_mask** (*bool*, optional) – Return mask of True/False instead of values

Returns **values** – Array of values/validity from the map.

Return type *np.ndarray*

property is_integer_map

Check that the map is an integer map

Returns **is_integer_map**

Return type *bool*

property is_rec_array

Check that the map is a recArray map.

Returns **is_rec_array**

Return type *bool*

property is_unsigned_map

Check that the map is an unsigned integer map

Returns **is_unsigned_map**

Return type *bool*

property is_wide_mask_map

Check that the map is a wide mask

Returns **is_wide_mask_map**

Return type *bool*

classmethod make_empty (*nside_coverage*, *nside_sparse*, *dtype*, *primary=None*, *sentinel=None*,
wide_mask_maxbits=None, *metadata=None*)

Make an empty map with nothing in it.

Parameters

- **nside_coverage** (*int*) – Nside for the coverage map
- **nside_sparse** (*int*) – Nside for the sparse map
- **dtype** (*str* or *list* or *np.dtype*) – Datatype, any format accepted by numpy.
- **primary** (*str*, optional) – Primary key for recarray, required if dtype has fields.
- **sentinel** (*int* or *float*, optional) – Sentinel value. Default is *hp.UNSEEN* for floating-point types, and minimum int for int types.
- **wide_mask_maxbits** (*int*, optional) – Create a “wide bit mask” map, with this many bits.
- **metadata** (*dict*-like, optional) – Map metadata that can be stored in FITS header format.

Returns **healSparseMap** – HealSparseMap filled with sentinel values.

Return type *HealSparseMap*

classmethod make_empty_like (*sparsemap*, *nside_coverage=None*, *nside_sparse=None*,
dtype=None, *primary=None*, *sentinel=None*,
wide_mask_maxbits=None, *metadata=None*)

Make an empty map with the same parameters as an existing map.

Parameters

- **sparsemap** (*HealSparseMap*) – Sparse map to use as basis for new empty map.

- **nside_coverage** (*int*, optional) – Coverage nside, default to sparsemap.nside_coverage
- **nside_sparse** (*int*, optional) – Sparse map nside, default to sparsemap.nside_sparse
- **dtype** (*str* or *list* or *np.dtype*, optional) – Datatype, any format accepted by numpy. Default is sparsemap.dtype
- **primary** (*str*, optional) – Primary key for recarray. Default is sparsemap.primary
- **sentinel** (*int* or *float*, optional) – Sentinel value. Default is sparsemap._sentinel
- **wide_mask_maxbits** (*int*, optional) – Create a “wide bit mask” map, with this many bits.
- **metadata** (*dict*-like, optional) – Map metadata that can be stored in FITS header format.

Returns **healSparseMap** – HealSparseMap filled with sentinel values.

Return type *HealSparseMap*

property metadata

Return the metadata dict.

Returns **metadata**

Return type *dict*

property nside_coverage

Get the nside of the coverage map

Returns **nside_coverage**

Return type *int*

property nside_sparse

Get the nside of the sparse map

Returns **nside_sparse**

Return type *int*

property primary

Get the primary field

Returns **primary**

Return type *str*

classmethod read (*filename*, *nside_coverage=None*, *pixels=None*, *header=False*)

Read in a HealSparseMap.

Parameters

- **filename** (*str*) – Name of the file to read. May be either a regular HEALPIX map or a HealSparseMap
- **nside_coverage** (*int*, optional) – Nside of coverage map to generate if input file is healpix map.
- **pixels** (*list*, optional) – List of coverage map pixels to read. Only used if input file is a HealSparseMap
- **header** (*bool*, optional) – Return the fits header as well as map? Default is False.

Returns

- **healSparseMap** (*HealSparseMap*) – HealSparseMap from file, covered by pixels

- **header** (*fitsio.FITSHDR* or *astropy.io.fits* (if `header=True`)) – Fits header for the map file.

set_bits_pix (*pixels, bits, nest=True*)

Set bits of a wide_mask map.

Parameters

- **pixels** (*np.ndarray*) – Integer array of sparse_map pixel values
- **bits** (*list*) – List of bits to set

update_values_pix (*pixels, values, nest=True*)

Update the values in the sparsemap for a list of pixels.

Parameters

- **pixels** (*np.ndarray*) – Integer array of sparse_map pixel values
- **values** (*np.ndarray*) – Value or Array of values. Must be same type as sparse_map

property valid_pixels

Get an array of valid pixels in the sparse map.

Returns valid_pixels

Return type *np.ndarray*

valid_pixels_pos (*lonlat=False, return_pixels=False*)

Get an array with the position of valid pixels in the sparse map.

Parameters

- **lonlat** (*bool*, optional) – If True, input angles are longitude and latitude in degrees. Otherwise, they are co-latitude and longitude in radians.
- **return_pixels** (*bool*, optional) – If true, return valid_pixels / co-lat / co-lon or valid_pixels / lat / lon instead of lat / lon

Returns positions – By default it will return a tuple of the form (*theta, phi*) in radians unless *lonlat = True*, for which it will return (*ra, dec*) in degrees. If *return_pixels = True*, valid_pixels will be returned as first element in tuple.

Return type *tuple*

property wide_mask_maxbits

Get the maximum number of bits stored in the wide mask.

Returns wide_mask_maxbits – Maximum number of bits. 0 if not wide mask.

Return type *int*

property wide_mask_width

Get the width of the wide mask

Returns wide_mask_width – Width of wide mask array. 0 if not wide mask.

Return type *int*

write (*filename, clobber=False*)

Write heal HealSparseMap to filename. Use the *metadata* property from the map to persist additional information in the fits header.

Parameters

- **filename** (*str*) – Name of file to save
- **clobber** (*bool*, optional) – Clobber existing file? Default is False.

8.1.2 HealSparseRandoms

`healsparse.healSparseRandoms.make_uniform_randoms` (*sparse_map*, *n_random*, *rng=None*)

Make an array of uniform randoms.

Parameters

- **sparse_map** (*healsparse.HealSparseMap*) – Sparse map object
- **n_random** (*int*) – Number of randoms to generate
- **rng** (*np.random.RandomState*, optional) – Pre-set Random number generator. Default is `None`.

Returns

- **ra_array** (*np.ndarray*) – Float array of RAs (degrees)
- **dec_array** (*np.ndarray*) – Float array of declinations (degrees)

`healsparse.healSparseRandoms.make_uniform_randoms_fast` (*sparse_map*, *n_random*, *nside_randoms=8388608*, *rng=None*)

Make an array of uniform randoms.

Parameters

- **sparse_map** (*healsparse.HealSparseMap*) – Sparse map object
- **n_random** (*int*) – Number of randoms to generate
- **nside_randoms** (*int*, optional) – Nside for pixel centers to select random points
- **rng** (*np.random.RandomState*, optional) – Pre-set Random number generator. Default is `None`.

Returns

- **ra_array** (*np.ndarray*) – Float array of RAs (degrees)
- **dec_array** (*np.ndarray*) – Float array of declinations (degrees)

8.1.3 Operations

`healsparse.operations.and_intersection` (*map_list*)

Bitwise or a list of `HealSparseMaps` as an intersection. Only pixels that are valid in all the input maps will have valid values in the output. Only works on integer maps.

Parameters *map_list* (list of *HealSparseMap*) – Input list of maps to bitwise and

Returns *result* – Bitwise and of maps

Return type *HealSparseMap*

`healsparse.operations.and_union` (*map_list*)

Bitwise and a list of `HealSparseMaps` as a union. Empty values will be treated as 0s in the bitwise and, and the output map will have a union of all the input map pixels. Only works in integer maps.

Parameters *map_list* (list of *HealSparseMap*) – Input list of maps to bitwise and

Returns *result* – Bitwise and of maps

Return type *HealSparseMap*

`healsparse.operations.max_intersection (map_list)`

Element-wise maximum of the intersection of a list of the HealSparseMaps.

Parameters `map_list` (*list of HealSparseMap*) – Input list of maps to compute the maximum of

Returns `result` – Element-wise maximum of maps

Return type *HealSparseMap*

`healsparse.operations.max_union (map_list)`

Element-wise maximum of the union of a list of HealSparseMaps.

Parameters `map_list` (*list of HealSparseMap*) – Input list of maps to compute the maximum of

Returns `result` – Element-wise maximum of maps

Return type *HealSparseMap*

`healsparse.operations.min_intersection (map_list)`

Element-wise minimum of the intersection of a list of HealSparseMaps.

Parameters `map_list` (*list of HealSparseMap*) – Input list of maps to compute the minimum of

Returns `result` – Element-wise minimum of maps

Return type *HealSparseMap*

`healsparse.operations.min_union (map_list)`

Element-wise minimum of the union of a list of HealSparseMaps.

Parameters `map_list` (*list of HealSparseMap*) – Input list of maps to compute the minimum of

Returns `result` – Element-wise minimum of maps

Return type *HealSparseMap*

`healsparse.operations.or_intersection (map_list)`

Bitwise or a list of HealSparseMaps as an intersection. Only pixels that are valid in all the input maps will have valid values in the output. Only works on integer maps.

Parameters `map_list` (*list of HealSparseMap*) – Input list of maps to bitwise or

Returns `result` – Bitwise or of maps

Return type *HealSparseMap*

`healsparse.operations.or_union (map_list)`

Bitwise or a list of HealSparseMaps as a union. Empty values will be treated as 0s in the bitwise or, and the output map will have a union of all the input map pixels. Only works in integer maps.

Parameters `map_list` (*list of HealSparseMap*) – Input list of maps to bitwise or

Returns `result` – Bitwise or of maps

Return type *HealSparseMap*

`healsparse.operations.product_intersection (map_list)`

Compute the product of a list of HealSparseMaps as an intersection. Only pixels that are valid in all the input maps will have valid values in the output.

Parameters `map_list` (*list of HealSparseMap*) – Input list of maps to take the product

Returns `result` – Product of maps

Return type *HealSparseMap*

`healsparse.operations.product_union(map_list)`

Compute the product of a list of HealSparseMaps as a union. Empty values will be treated as 1s in the product, and the output map will have a union of all the input map pixels.

Parameters `map_list` (list of *HealSparseMap*) – Input list of maps to take the product

Returns `result` – Product of maps

Return type *HealSparseMap*

`healsparse.operations.sum_intersection(map_list)`

Sum a list of HealSparseMaps as an intersection. Only pixels that are valid in all the input maps will have valid values in the output.

Parameters `map_list` (list of *HealSparseMap*) – Input list of maps to sum

Returns `result` – Summation of maps

Return type *HealSparseMap*

`healsparse.operations.sum_union(map_list)`

Sum a list of HealSparseMaps as a union. Empty values will be treated as 0s in the summation, and the output map will have a union of all the input map pixels.

Parameters `map_list` (list of *HealSparseMap*) – Input list of maps to sum

Returns `result` – Summation of maps

Return type *HealSparseMap*

`healsparse.operations.ufunc_intersection(map_list, func, filler_value=0)`

Apply numpy ufunc to the intersection of a list of HealSparseMaps.

Parameters

- **map_list** (list of *HealSparseMap*) – Input list of maps where the operation is applied
- **func** (*np.ufunc*) – Numpy universal function to apply
- **filler_value** (*int* or *float*) – Starting value

Returns `result` – Resulting map

Return type *HealSparseMap*

`healsparse.operations.ufunc_union(map_list, func, filler_value=0)`

Apply numpy ufunc to the union of a list of HealSparseMaps.

Parameters

- **map_list** (list of *HealSparseMaps*) – Input list of maps where the operation is applied
- **func** (*np.ufunc*) – Numpy universal function to apply
- **filler_value** (*int* or *float*) – Starting value and filler for the union

Returns `result` – Resulting map

Return type *HealSparseMap*

`healsparse.operations.xor_intersection(map_list)`

Bitwise xor a list of HealSparseMaps as an intersection. Only pixels that are valid in all the input maps will have valid values in the output. Only works on integer maps.

Parameters `map_list` (list of *HealSparseMap*) – Input list of maps to bitwise xor

Returns `result` – Bitwise xor of maps

Return type *HealSparseMap*

`healsparse.operations.xor_union` (*map_list*)

Bitwise xor a list of *HealSparseMaps* as a union. Empty values will be treated as 0s in the bitwise or, and the output map will have a union of all the input map pixels. Only works in integer maps.

Parameters `map_list` (*list of HealSparseMap*) – Input list of maps to bitwise xor

Returns `result` – Bitwise xor of maps

Return type *HealSparseMap*

8.1.4 Geometry Library

class `healsparse.geom.Circle` (**, ra, dec, radius, value*)

Bases: *healsparse.geom.GeomBase*

`__init__` (**, ra, dec, radius, value*)

Parameters

- **ra** (*float*) – ra in degrees
- **dec** (*float*) – dec in degrees
- **radius** (*float*) – radius in degrees
- **value** (*number*) – Value for pixels in the map

`__repr__` ()

Return repr(self).

property `dec`

get the dec value

get_pixels (**, nside*)

get the pixels associated with this circle

Parameters `nside` (*int*) – Nside for the pixels

property `ra`

get the ra value

property `radius`

get the radius value

class `healsparse.geom.GeomBase`

Bases: *object*

base class for geometric objects that can convert themselves to maps

`__weakref__`

list of weak references to the object (if defined)

get_map (**, nside_coverage, nside_sparse, dtype, wide_mask_maxbits=None*)

get a healsparse map corresponding to this geometric primitive

Parameters

- **nside_coverage** (*int*) – nside of coverage map
- **nside_sparse** (*int*) – nside of sparse map
- **dtype** (*np.dtype*) – dtype of the output array

- **wide_mask_maxbits** (*int*, optional) – Create a “wide bit mask” map, with this many bits.

Returns

Return type *HealSparseMap*

get_map_like (*sparseMap*)

Get a healsparse map corresponding to this geometric primitive, with the same parameters as an input *sparseMap*.

Parameters **sparseMap** (*healsparse.HealSparseMap*) – Input map to match parameters

Returns

Return type *HealSparseMap*

get_pixels (*, *nside*)

get pixels for this map

Parameters **nside** (*int*) – Nside for the pixels

property is_integer_value

Check if the value is an integer type

property value

get the value to be used for all pixels in the map

class *healsparse.geom.Polygon* (*, *ra*, *dec*, *value*)

Bases: *healsparse.geom.GeomBase*

__init__ (*, *ra*, *dec*, *value*)

represent a polygon

both counter clockwise and clockwise order for polygon vertices works

Parameters

- **ra** (*array*) – ra of vertices in degrees, size [nvert]
- **dec** (*array*) – dec of vertices in degrees, size [nvert]
- **value** (*number*) – Value for pixels in the map

__repr__ ()

Return repr(self).

property dec

get the dec value

get_pixels (*, *nside*)

get the pixels associated with this polygon

Parameters **nside** (*int*) – Nside for the pixels

property ra

get the ra value

property vertices

get the dec value

healsparse.geom.realize_geom (*geom*, *smap*, *type*='or')

Realize geometry objects in a map

Parameters

- **geom** (*geometric primitive or list thereof*) – List of Geom objects, e.g. Circle, Polygon
- **smap** (*HealSparseMaps*) – The map in which to realize the objects
- **type** (*string*) – Way to combine the list of geometric objects. Default is to “or” them

8.1.5 HealSparseCoverage

class `healsparse.healSparseCoverage.HealSparseCoverage` (*cov_index_map*,
nside_sparse)

Bases: `object`

Class to define a HealSparseCoverage map

__init__ (*cov_index_map*, *nside_sparse*)

Instantiate a HealSparseCoverage map.

Returns `healSparseCoverage`

Return type *HealSparseCoverage*

__weakref__

list of weak references to the object (if defined)

append_pixels (*sparse_map_size*, *new_cov_pix*, *check=True*, *copy=True*)

Append new pixels to the coverage map

Parameters

- **sparse_map_size** (*int*) – Size of current sparse map
- **new_cov_pix** (*np.ndarray*) – Array of new coverage pixels

property bit_shift

Get the `bit_shift` for the coverage map

Returns `bit_shift` – Number of bits to shift from coarse to fine maps

Return type *int*

cov_pixels (*sparse_pixels*)

Get coverage pixel numbers (nest) from a set of sparse pixels.

Parameters **sparse_pixels** (*np.ndarray*) – Array of sparse pixels

Returns `cov_pixels` – Coverage pixel numbers (nest format)

Return type *np.ndarray*

property coverage_mask

Get the boolean mask of the coverage map.

Returns `cov_mask` – Boolean array of coverage mask.

Return type *np.ndarray*

initialize_pixels (*cov_pix*)

Initialize pixels in the index map

Parameters **cov_pix** (*np.ndarray*) – Array of coverage pixels

classmethod make_empty (*nside_coverage*, *nside_sparse*)

Make an empty coverage map.

Parameters

- **nside_coverage** (*int*) – Healpix nside for the coverage map
- **nside_sparse** (*int*) – Healpix nside for the sparse map

Returns **healSparseCoverage** – HealSparseCoverage from file

Return type *HealSparseCoverage*

classmethod **make_from_pixels** (*nside_coverage, nside_sparse, cov_pixels*)
Make an empty coverage map.

Parameters

- **nside_coverage** (*int*) – Healpix nside for the coverage map
- **nside_sparse** (*int*) – Healpix nside for the sparse map
- **cov_pixels** (*np.ndarray*) – Array of coverage pixels

Returns **healSparseCoverage** – HealSparseCoverage from file

Return type *HealSparseCoverage*

property **nfine_per_cov**

Get the number of fine (sparse) pixels per coarse (coverage) pixel

Returns **nfine_per_cov** – Number of fine (sparse) pixels per coverage pixel

Return type *int*

property **nside_coverage**

Get the nside of the coverage map

Returns **nside_coverage**

Return type *int*

property **nside_sparse**

Get the nside of the associated sparse map

Returns **nside_sparse**

Return type *int*

classmethod **read** (*filename_or_fits*)

Read in HealSparseCoverage.

Returns **healSparseCoverage** – HealSparseCoverage from file

Return type *HealSparseCoverage*

8.1.6 Concatenation

`healsparse.cat_healsparse_files.cat_healsparse_files` (*file_list*, *outfile*,
check_overlap=False, *clobber=False*, *in_memory=False*,
nside_coverage_out=None)

Concatenate healsparse files together in a memory-efficient way.

Parameters

- **file_list** (*list of str*) – List of filenames to concatenate
- **outfile** (*str*) – Output filename

- **check_overlap** (*bool*, optional) – Check that each file has a unique sparse map. This may be slower.
- **clobber** (*bool*, optional) – Clobber existing outfile
- **in_memory** (*bool*, optional) – Do operations in-memory (required unless fitsio is available).
- **nside_coverage_out** (*int*, optional) – Output map with specific nside_coverage. Default is nside_coverage of first map in file_list.

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