Roman skymap tessellation

Dario Fadda

Objectives:

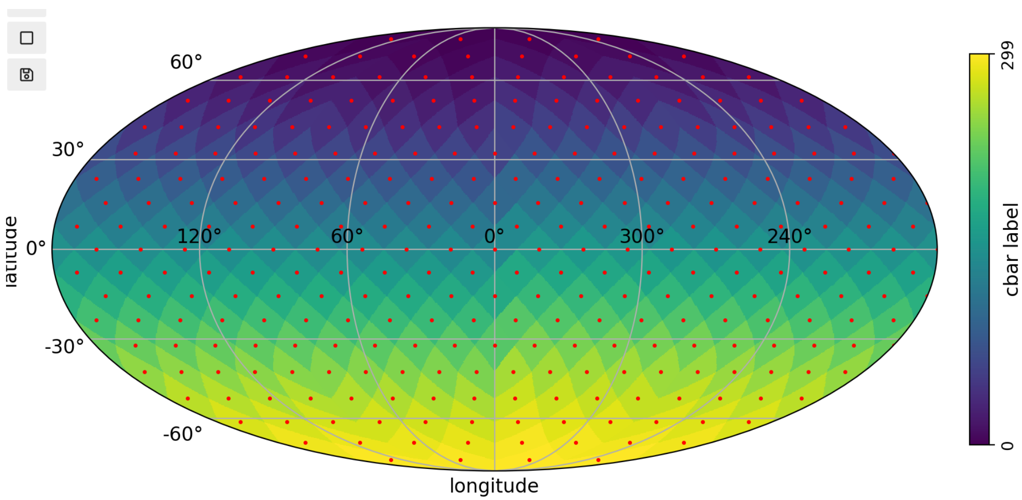
- Simple and unique way to tessellate the sphere
- Approximately square tiles with similar area
- Tiles with tangential projection NE oriented
- Tiles big enough to be scientifically useful
- Strategy to chunk tiles for archival purposes

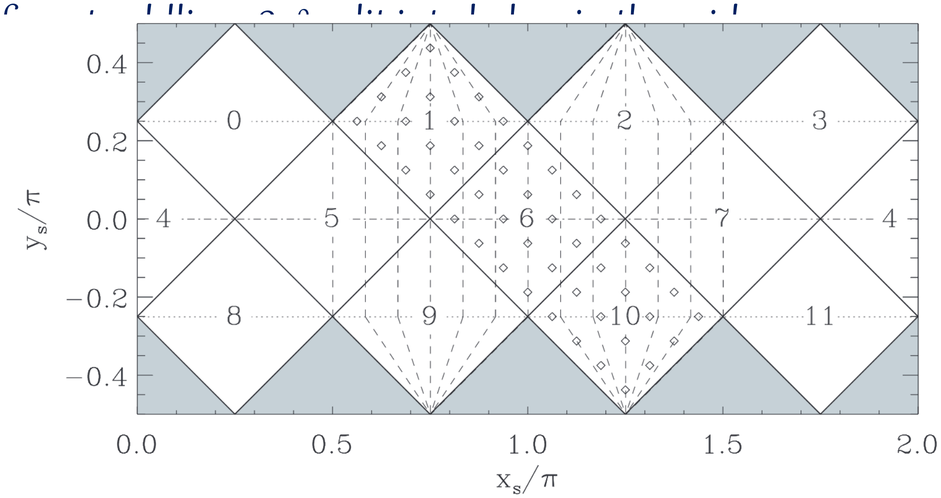
HEALPix

A smart way to tessellate the sphere is using the HEALPix tessellation.

HEALPix projections are uninterrupted, equal-area, pseudo-cylindrical projections.

- Equal area: regions with equal area on the sphere have equal area in the plane of projection
- Parallels are projected as horizontal lines
- Parallels are uniformly divided

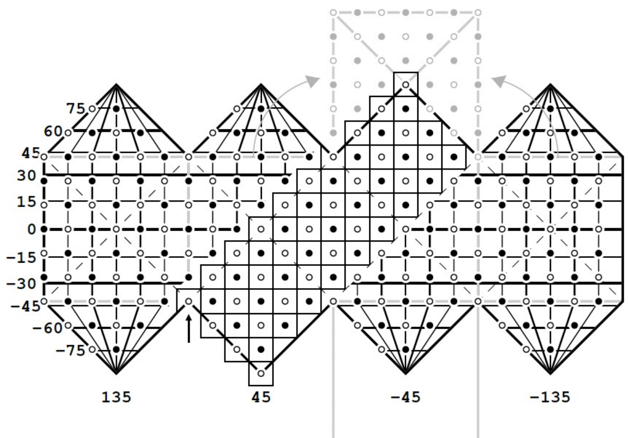


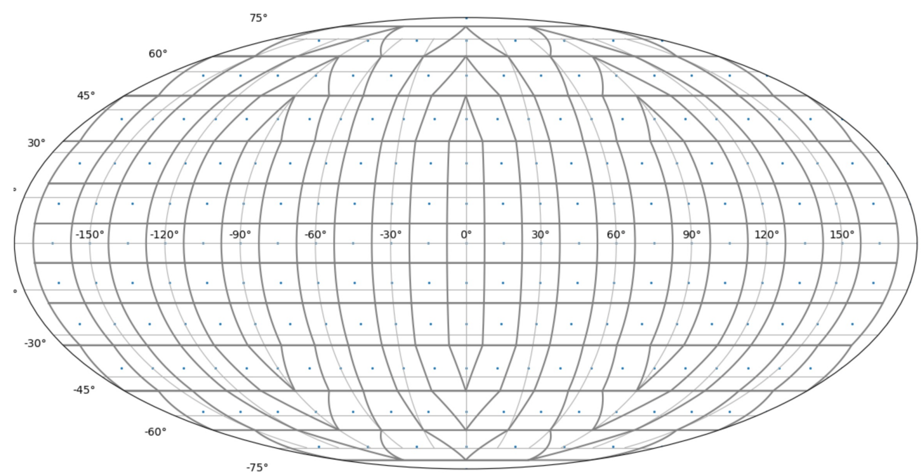


Double Pixelization

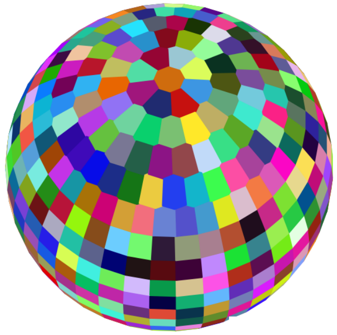
HEALPix can be represented with squares (and pixels) oriented at 45°. To obtain something more familiar to astronomers and more efficient for tangential projections, we can use the procedure of double pixelization: adding a center to the left of each HEALPix center (Calabretta & Roukema, 2007, MN 381:872).

This tessellation partitions the projected sphere in equal area squares (once healpix projected), except for the squares at the 8 corners on the latitude between cylindrical and polar projection. These pixels have an area 3/4 of the other pixels' area. The missing areas are used by the two extra pixels on the poles.

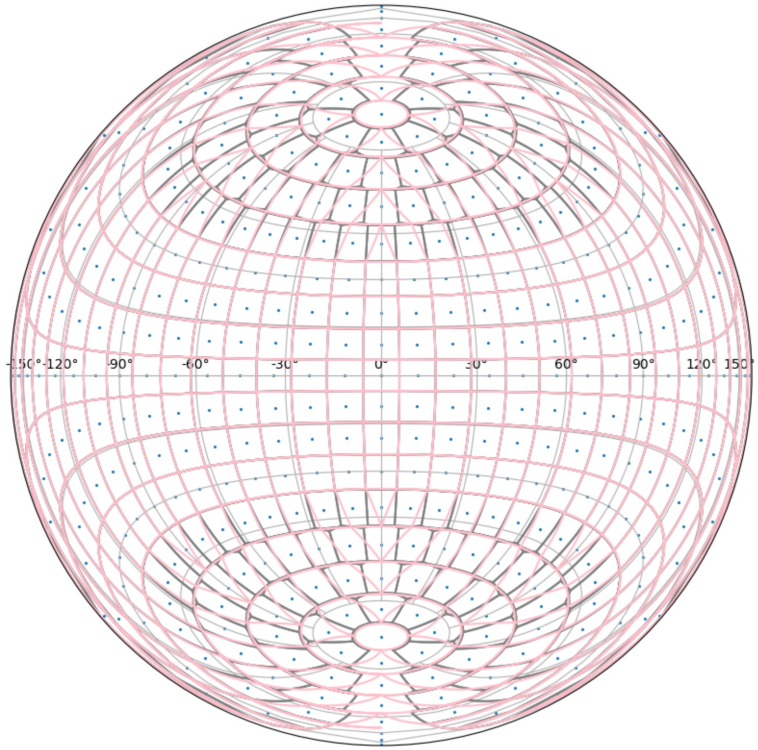




Tangential projection



Comparison between double pixelization (pink) and Voronoi (gray)

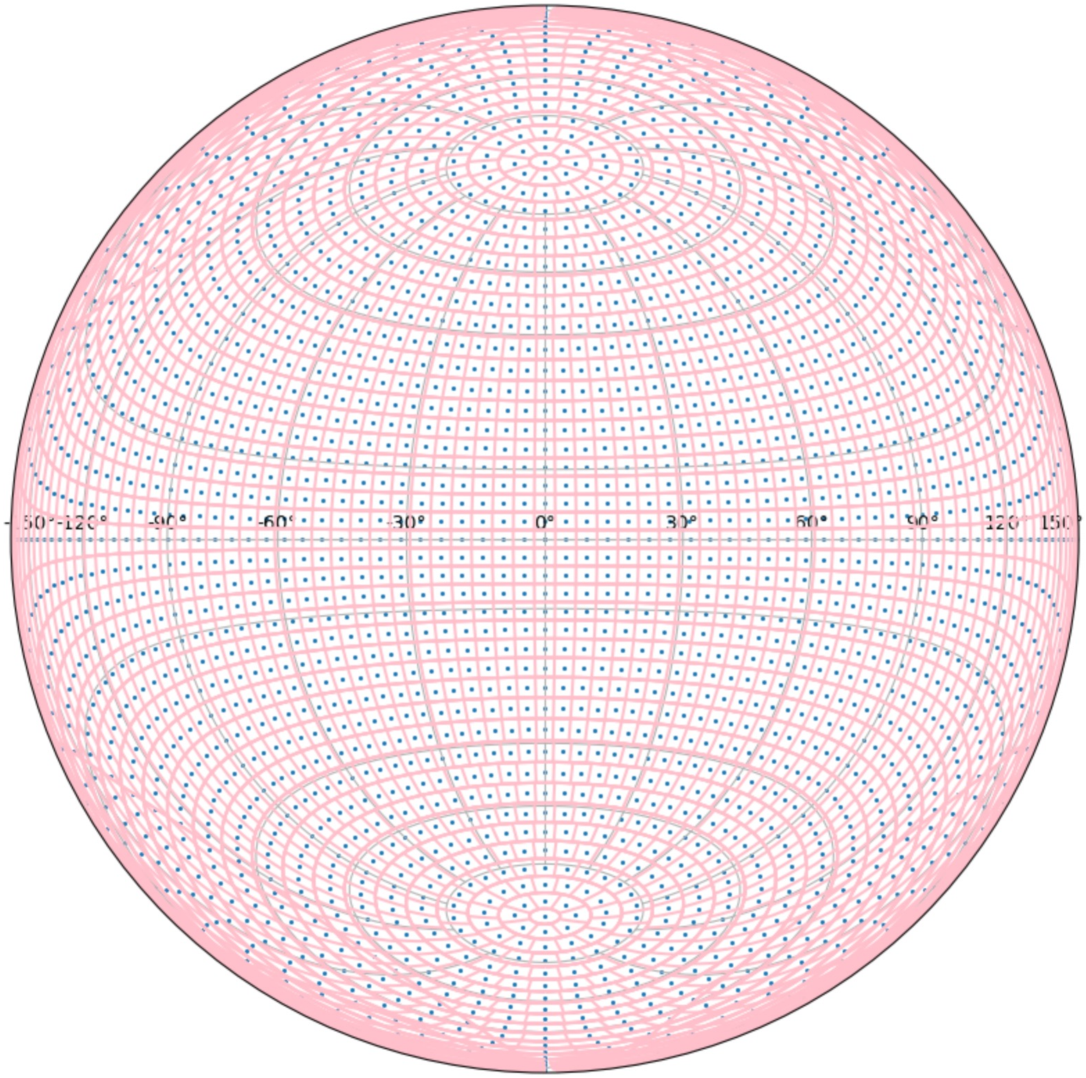


If we use a Voronoi tessellation using as seeds the double pixelization centers, we obtain a tessellation which can be used to obtain tangential projection mosaics of approximately rectangular shape (less and less towards the poles). Going towards the poles, because of the shift in the center positions, the lower and upper limits become more jagged.

Roman tessellation

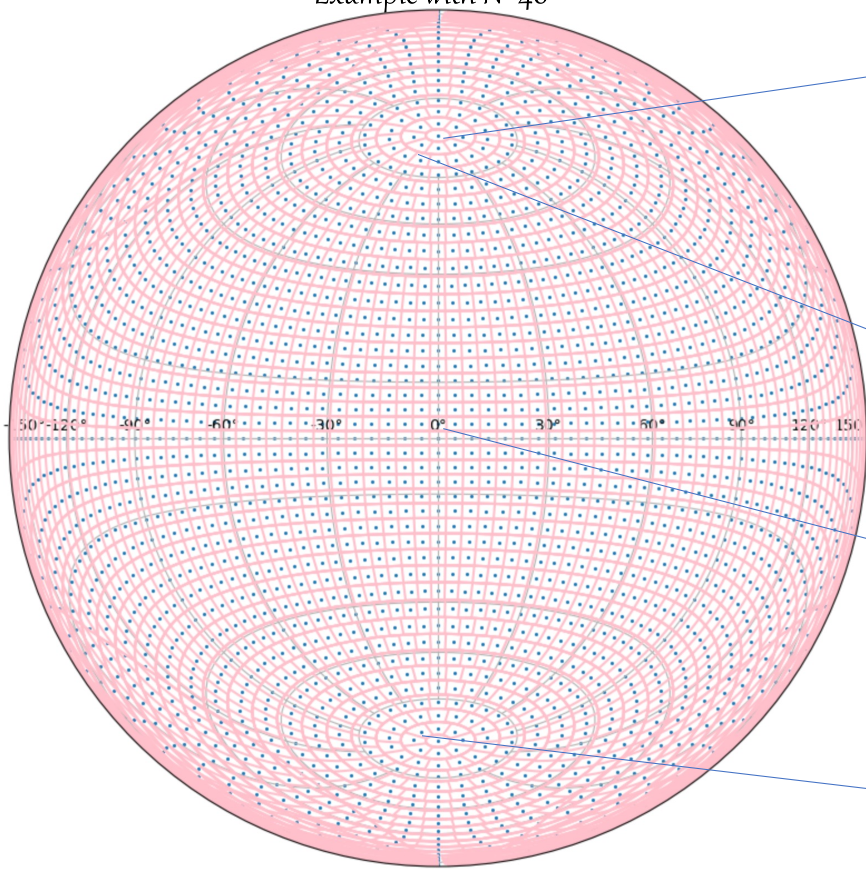
We can define a more regular tessellation by using the double pixelization centers and limits in latitude. As limits in longitude, we can simply use the middle latitude between two contiguous points along a ring.

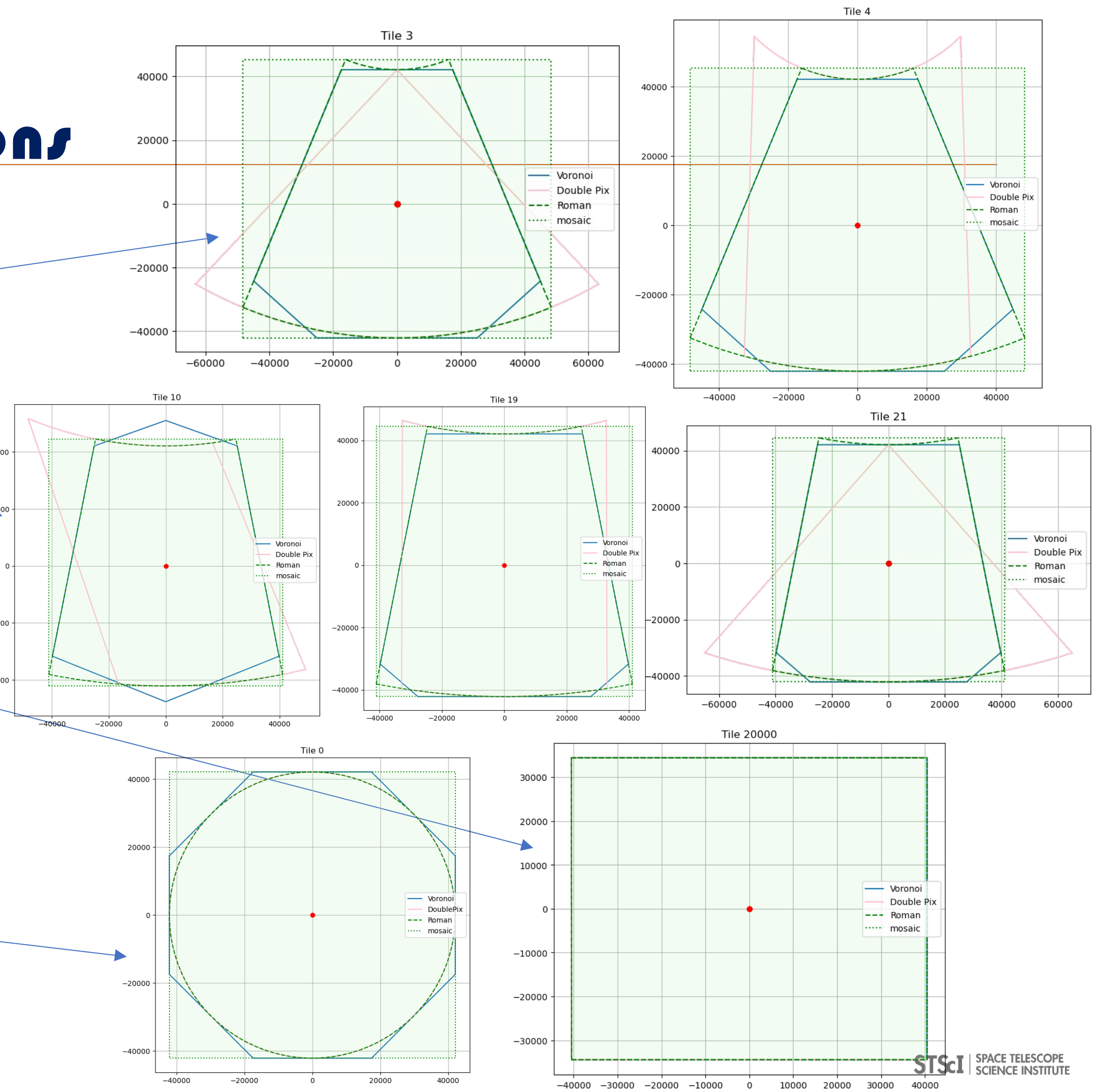
In the example, the sphere is tessellated with 2400 tiles with 4° side (corresponding to N=10).



Tangential projections

Example with N=40





Dario Fadda –Feb 26, 2024

Definition of the tessellation

Operative definition

1. Obtain centers and limits in latitude of double pixelization with a number of points linked to the size of the final tile

2. For each center, define a tile with limits the two values of latitude and the difference in longitude equivalent to the distance in longitude between consecutive centers on a ring.

3. Mosaics will be obtained by considering the images overlapping each tile and projecting them using a tangential projection with point of contact defined by the center of the tile. The mosaic will be rectangular with NaNs where there are no images. A mask will be defined to select pixels belonging to the relative tile.

Tiles' WCS

- For each tessell we will have:

1. Limits in RA, Dec
2. Center for tangential projection
3. Orientation (NE for all tiles except for the pole ones which can have any orientation in principle)
4. Pixel size
5. N_x and N_y of the mosaic (reference pixel at the center of the mosaic)

- Each tile will have an index which can be used in a source catalog to identify the sky region where a source has been detected.
- The files relative to each tile can use the RA-Dec of the center in their name for an easy identification. The header will contain the tessellation index.

Core and overlapping region

Each mosaic of a tile will have:

- Core region, corresponding to the pixels in the tile
- Overlapping region, a padding around the core region used to better detect sources which fall on the border of the tile

The extension of the overlapping region is determined by the size of the sources which will be considered in the catalog.

A good guess is including slightly extended sources (i.e. galaxies at high redshift).

We can choose sources with a size of 1" (as Euclid does) and decide to add a few arcseconds to the border. To be on the safe side, 5" which will correspond to approximately 50 pixels with a pixel size of 0.11" (or 100 with a 0.05" pixel size).

The overlapping region can be also used to match the sky of contiguous tile.

Considerations about the size of the pixel

Element name	Min (µm)	Max (µm)	Center (µm)	Width (µm)	R	PSF FWHM (arcsec) *
F062	0.48	0.76	0.620	0.280	2.2	**0.058**
F087	0.76	0.977	0.869	0.217	4	**0.073**
F106	0.927	1.192	1.060	0.265	4	**0.087**
F129	1.131	1.454	1.293	0.323	4	**0.105**
F158	1.380	1.774	1.577	0.394	4	**0.127**
F184	1.683	2.000	1.842	0.317	5.81	**0.151**
F213	1.95	2.30	2.125	0.35	6.07	0.175
F146	0.927	2.000	1.464	1.030	1.42	**0.105**

The size of the pixel is function of the PSF of the telescope/instrument. The pixel of WFI is 0.11”, which means that the PSF is undersampled. However, dithering allows one to recover a resolution higher than the size of the detector pixel.

If all the images will be degraded to the worst PSF (~0.12”) to allow a photometric comparison, the minimum resampling should be at least two pixels for PSF (Shannon’s criterion).

We assume a 0.05” pixel size.

Computational considerations on the size of a tile

- The tile size is mainly limited by the computational capabilities of the reduction pipeline and the source extraction software.

- Outlier rejection (many images are in memory at the same time)
- Reprojection and coaddition (ditto)
- Source extraction (although in this case a more extended region could be beneficial to get rid of extended background emission for point source extraction)

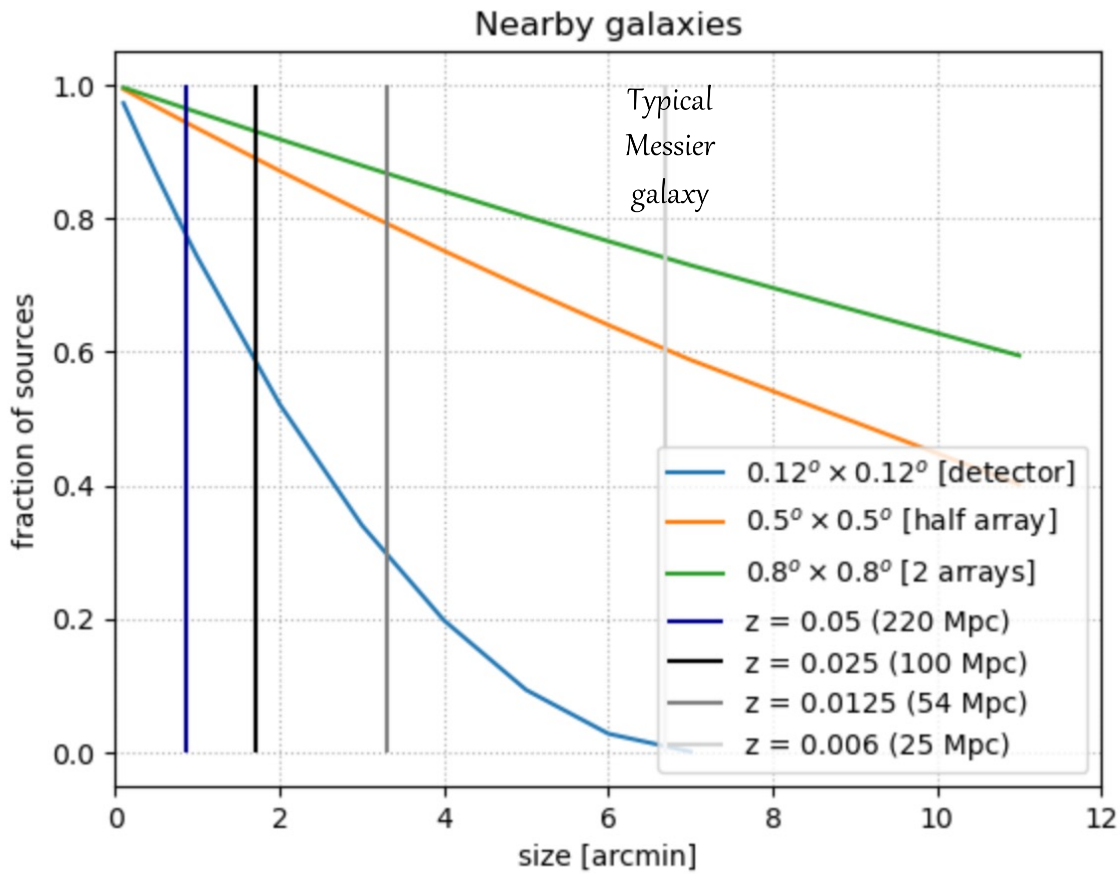
- Another factor is the load on the servers to download data.

- Finally, the matching of the sky background could be in principle decoupled from the mosaicking pipeline. For a finer sky background matching, computed on a single tessell, it is beneficial to have a larger field to compute a more stable background

Astronomical considerations on the size of a tile

Tile-size mosaics will be stored in the archive. If the tiles are too small, many extended sources will be divided in several tiles. The plot shows the percentage of galaxies which can be retrieved directly from the archive as a function of tile's size and galaxy's distance.
A galaxy is considered detected if it falls completely inside a tile.

A large tile is preferred also for projection reasons. Instead of reprojecting small images into larger mosaics, the user can start directly with a larger area projection done in the optimal way.



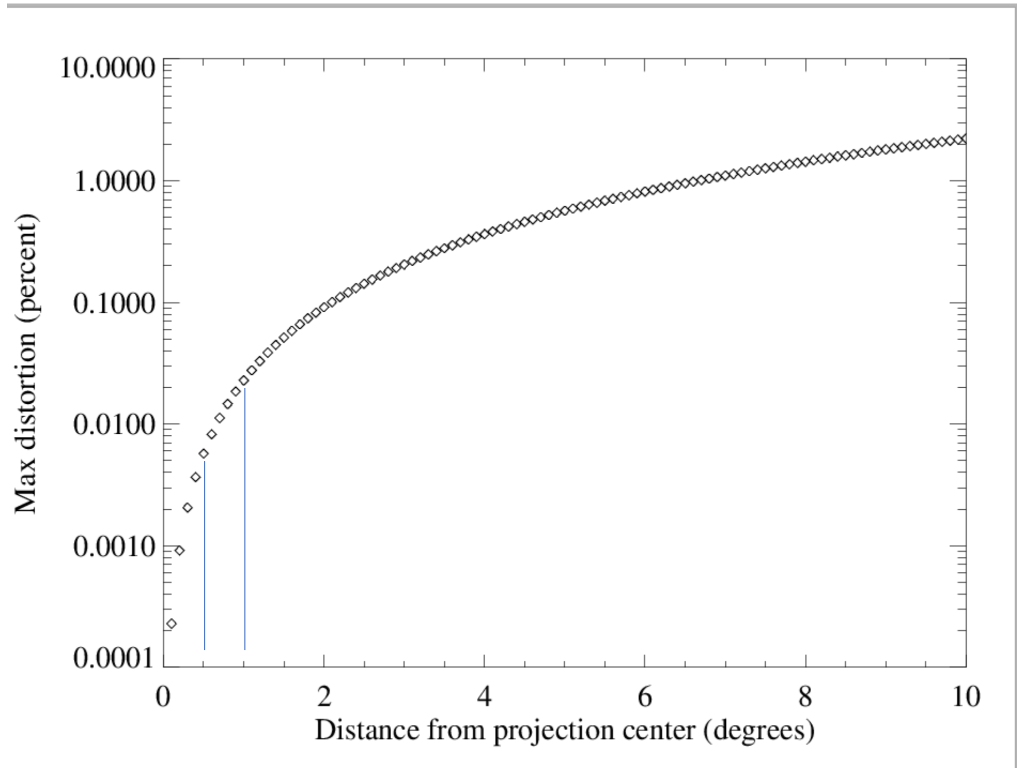
Andromeda size galaxies (~50kpc) at different z

Size of tile and mosaic distortion

Distortion is not an issue for a mosaic extending up to 2°.

With a 1° x 1° mosaic, the maximum distortion is 0.006 %.

Extending to a 2° x 2° mosaic, the maximum distortion is 0.02 %.



Plot created by Stefano Casertano

More details

A tile with side of 1° can be obtained with double pixelization and N=40.

It will results in 38000 tiles to cover the entire celestial sphere, each one of 74K x 74K of 0.05" size pixels.

Such a tile can be chunked in 10 x 10 pieces to have more manageable sizes.

Alternatively, with N = 20 we obtain 9600 tiles with 2° sides which can be chunked into 20 x 20 pieces.

Each detector image can be easily assigned to a primary tile and secondary tiles.

A primary tile is a tile where the center of the detector falls on a tile. A secondary tile will have its center falling at a distance of half detector from the border of the extended area. So, it will contribute to the mosaic of the tile.

Each mosaic will have a mask with 1 if the area is in the tile, 0 otherwise. Pixels beyond the extended area of the tile can be put to NaN (or a fixed number) to exclude areas with incomplete coverage beyond the source extraction region.

Git repository

The software to compute the tessell's centers and limits is available in the git repository:

https://grit.stsci.edu/roman/skymap

The notebook contains the examples presented and the way to obtain a fits table with info about the tessells and the way to read it in Python.

A version of this presentation is available at the same git repository.

Advantages

1. **Simple definition** Tiles defined by 4 numbers (min e max latitudes and longitudes, except for the polar caps which need only one number, the limit latitude)

2. **High degree of symmetry** Tiles are defined along rings, have similar area, and they have four planes of symmetry along the sphere

3. **Simple overlap definition** Easy to define margin of overlap by adding an extension in latitude and longitude

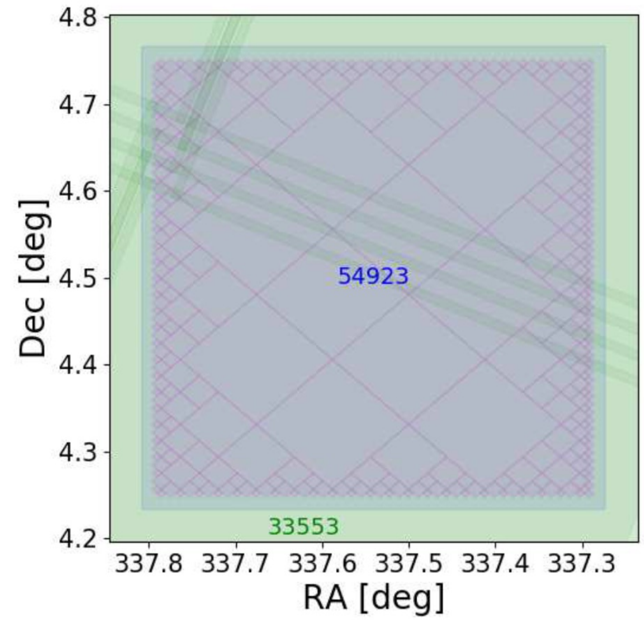
4. **Unique tessellation of the sphere** For each mosaic (rectangle) a mask defining the pixels on the relative tessel is defined. This makes easy to compile catalogs of sources with unique entries. Sources detected on the overlap regions are not considered.

5. **Background matching between tiles** The little overlap between contiguous tiles can be used to perform background matching among mosaics of the different tiles. The offsets computed can be stored in each image associated to the tile for producing mosaics from original images covering different regions. Such overlaps between two tiles have to be reprojected on a common tangential projection before comparison. Since the overlapping region is equidistant from the respective centers, there will be a similar degree of distortion. Moreover, since the projection is oriented towards the pole, the pixels are similarly oriented.

What does Euclid ?

The orientation of the tiles is along RA and Dec, and the tiles are placed in stripes of constant Dec. Each tile has an extended area and a core area. While the extended areas of adjacent tiles have an overlap to avoid border problems in the measurements, the core areas of any two tiles do not overlap. The extended areas and the core areas of all tiles cover the entire Euclid survey area with and without overlap, respectively. Object detection and property measurements are done on the extended tile area, but the resulting objects catalogs are stored only for the tile core area to avoid detecting objects more than once. The core areas of the tiles are defined in healpix indices in order to avoid projection effects when selecting the objects in the core.

- ***extended tile area is 32 ′ × 32′ large (resolution of Euclide is lower than Roman)***
- ***the tiles start at RA = 0° and are placed in stripes at constant Dec***
- ***the tile sizes are adjusted at the survey boundaries and when closing the stripes at RA ≈360°***
- ***the tile core area is defined using healpix of order 13***
- ***the tile overlap guarantees a minimal distance of at least 30 ′′ , hence (assuming symmetry) the solution is sensitive to objects with size smaller than 1'***



An Euclid tile