

This repository uses a modified old version of various files from the papaya2-library (<https://github.com/morphometry/papaya2>). PNGs are encoded with lodePNG (<https://lodev.org/lodepng/>).

Fits-files are read and written using CCFits (<https://heasarc.gsfc.nasa.gov/fitsio/CCfits/html/index.html>, separate installation required).

If you are using banana for your own work, please cite the accompanying paper on bubble detection in the Magellanic Clouds (DOI: 10.1051/0004-6361/202040153, arXiv: 2108.11641).

Banana is to be used for a variety of MT/MF related functions. By default, it creates Minkowski maps of the absolute value of the IMT  $\psi_s$  for a round window with diameter given by *smooth* for the regions above the brightness threshold given by *maxt*. Alternatively (*3d true*), it takes *numt* logarithmically spaced thresholds from *mint* to *maxt* and saves a fits file with *numt* layers.

Can also calculate the complex average of the Minkmaps at the different thresholds (*avg true*, this is very useful for real data) or the average of the absolute value (additionally *abs\_avg true*). Phases can be saved instead with *arg true*. Commands are discussed in detail in the list further below, here is a short overview.

*makeBanana true* leads to the calculation of various MF/MT for the specific areas of the image defined in the regions in *mask* (syntax see below) and the brightness thresholds given by *mint*, *maxt* and *numt*. For every object in the maskfile a separate output table is created. Saves to *outascii*.

*makePeach true* is similar to *makeBanana*, but varies the window size instead of the brightness threshold at the given *mask* regions. Saves one table for every object. Saves to *outascii*.

*makeHist true* expects a file containing names of files containing point coordinates given by stars command (syntax see below) and creates a histogram of the input file brightness at the position of the points. Bins are linearly spaced with parameters *mint*, *maxt* and *numt*. File identifier given by *histapp* appended to each file. Saves to *outascii*.

*makePointspread true* takes a list of files containing points in the same format as for *makeHist* and creates an image with a Gaussian of standard deviation given by *smooth* at the location of each star. Saves to *outpointsread*.

*makePNGs true* creates png files with a logarithmic brightness scale of the regions in *mask* with red given by *infile*, green by *greenfile* and blue by *bluefile*. *monochrome true* leads to creation of monochrome infile-based pngs. To remove single bright spots image can be eroded/dilated with diameter *erd* before. Saves to *outPNGs*

*makeHedgehog true* creates linedensity maps at given *smooth* and calls *makeBubbles true*. Uses parameters *lineThresh* and *lineScale* for threshold of bubble detection and scale factor for length of line. *smooth* value of Minkmap to which image is compared is hardcoded for several relevant smooth values and set to 3-smooth by default. Details see paper (DOI: 10.1051/0004-6361/202040153, arXiv: 2108.11641) or thesis (<https://theorie1.physik.uni-erlangen.de/research/theses/2020-ma-ccollischoen.html>). Saves line density map in *outlinedens* and bubbles in *outascii* and *objectDIR*.

*makeBubbles true* searches for bubbles in existing linedensity map using *lineScale* and *lineThresh*. Also see *makeHedgehog*. Saves bubbles in *outascii* and *objectDIR*.

*makePattern [linedensity/minkmap/infile/infile\_log]* creates a point pattern with intensity given by image according to command (*infile\_log* means using the logarithm of the file in *in*) and saves it as a table (can be read by R). Only takes image values larger than *lineThresh* into account (by default zero). *infile* can be smoothed with diameter given by *smooth* and

eroded/dilated with diameter *erd*. Saves pattern in *outascii*

Recommendations:

Set a suitable file identifier (e.g. wavelength) with *filePrefix* and the correct folders for text files, *minkmaps*, line densities, *pointspread*, and PNGs (*out\** commands), objects to be read/written (*objectDIR*).

Many of these functions require calculating the shift in pixel coordinates introduced by smoothing relative to the original file to convert back and forth between corresponding locations. This is done by saving the header variable *CRPIX1* of the original file and comparing it to that of the smoothed file. If *infile* is a smoothed file and thus already shifted, errors may occur.

Every command except the `filewithoutWCS` command demands either a number or `true/false` (`false` = anything except the word "true") as arguments. Give arguments separated by space after command

Syntax:

```

command Name of corresponding variable in source code, description

    in infilename, FITS file to be read

    mask maskfilename, File with names of object files to be included in the original-
        Banana or makePNGs or makePeach call (everything else masked per object)

boxesToExclude boxesToExcludeName, text file containing boxes (format see below) to be set
    to zero in infile. To be used for ignoring image errors.

    filePrefix wavelength, identification prefix for file to be used in further filenames, usu-
        ally wavelength. Default: "unspecified"

    stars histfile, list with one ds9 region file located in objectDIR per line contain-
        ing pixel coordinates of stars in original image for histogram/other statistics
        (without .reg-ending, added automatically)

    histapp histappendix, name appendix for histogram, enter anything besides histfile

    mint min_thresh, minimal threshold. Default: 0.1

    maxt max_thresh, maximal threshold or threshold for single threshold maps. De-
        fault: 40

    numt num_thresh number of (logarithmically spaced) thresholds to be considered.
        Default: 9

    outminmap outminmap, saving directory of Minkowski-map FITS file. Settings will be
        appended to the name. Default: ./

    outascii outfile/settings.resultDIR, saving directory of all output text files (ds9-
        bubbles, linemaps, banana tables, peach tables,...). Settings will be appended
        to the name. Default: ./

    outlinedens outlinedens/settings.linedensDIR, saving directory of line density file. De-
        fault: ./

    outpointspread outpointspread, saving directory of pointspread fits file Default: ./

    outPNGs settings.pngDIR, saving directory of PNGs. Default: ./

    objectDIR settings.objectDIR, saving directory of object files (box lists). Default: ./

    s s, rank of Minkowski tensor to be used ( $s = 0$  for perimeter,  $s = 1$  is used for
        Euler characteristic and  $s=4234$  for area here). Alternatively use area or euler
        commands. Default: 2

    area calculate area Minkowski functional. Equivalent to  $s = 4234$  (1337 for AREA).
        Takes no follow-up argument.
```

- euler calculate euler characteristic. Equivalent to  $s = 1$  (replaces  $\psi_1$  which is always equal to zero anyway). Takes no follow-up argument.
- smooth smooth, diameter of circle to be smoothed in marching-squares-map. Minkmap value calculated at locations of distance *smooth*/6 (usually sufficient). Set either *squaresize* or *smooth*
- squaresize *squaresize*, set size of squares Minkowski-map. If set, a square instead of a circle is used for Minkmap calculation and the mInkmap is calculated at every pixel position. Set either *squaresize* or *smooth*. Smooth recommended over *squaresize* for speed reasons.
- erd *erd*, set diameter of erosion/dilation (often called opening) smoothing of the infile(s) to be done before originalBanana/creating PNGs
- 3d threeD, if **true**: consider all different thresholds, else: consider only maximum. Default: false
- avg average, if **true**: average over all calculated thresholds, else: write 3D FITS file. Only relevant if **3d** is set. Defalut: false
- abs\_avg absolute\_avg, if **true**: calculate absolute values of maps first, then average. Only relevant if **avg** is set
- arg Take phase instead of absolute value of tensors. Default: false
- makeBanana makeBanana, if **true**: sets make\_minkmap to false, such that the IMTs of the whole (masked) image are calculated, possible to erode/dilate before with *erd* command. Default: false
- makePeach make\_peach, if **true**: sets make\_minkmap to false, calculates averaged (over maskfile) IMTs of given regions depending on smooth diameter. Relies on pre-existing minkmaps, saves output in outascii. smooth diameters used: 10, 20, 30, 40, 50, 60, 100, 150, 200, 250, 300, 450. Default: false
- makeHist makepointHist, if **true**: sets make\_minkmap to false, calculates histogram of point sources given in stars command for given file. Also creates histogram of whole image, saves output in outascii . Default: false
- makePointsread make\_pointsread, if **true**: sets make\_minkmap to false, calculates spread of point sources given in stars command for Gaussian point spread function and diameter given by smooth, specific width = smooth/2. Saves as FITS-file, saves output in outpointsread. Default: false
- makePattern make\_patternFromImage, linesorminkmap, Accepts "linedensity", "minkmap", "infile", or "infile\_log" as follow-up commands, creates an R-readable table with around 4-5000 points with the number of points proportional to the value at that square, saves in outascii. Input given by *in* command, output name either name of input file or wavelength (in case of "infile[.log]"). In-file gets smoothed with given windowsize and eroded/dilated with diameter *erd*, with *infile\_log* also logarithm taken before smoothing. Default: false/"linedensity"

- combineRegions** `combine_regions`, Takes all maskfiles given by *combination* and combines bubbles from smaller to larger size; set *mask* to name output. Outputs various formats: each combined bubble as objectfile containing its original boxes and maskfile listing them, ds9-readable files for each bubble containing all original boxes, R-readable plain table containing average centers of bubbles, ds9-regionfile containing average centers and sizes of all bubbles. Saves all in *outascii* or working directory
- combination** `combination`, Name of file containing all lists of bubbles to be compared and combined, one filename per line. Should be ordered by increasing size. Can use the automatically generated “bubbles\_sorted\_regionnames[...]”-files from bubble detection
- makePNGs** `makePNGs`, if **true**: sets `make_minkmap` to false, creates PNGs containing single objects either monochrome or with R = infile, G = greenfile, B = bluefile based on the objects in maskfile, possible to erode/dilate images before with `erd` command, saves output in *outPNGs* . Default: false
- monochrome** If **true**: make monochrome images based on just infile (default), else read greenfile and bluefile. Default: true
- greenfile** Filename of green layer of PNG.
- bluefile** Filename of blue layer of PNG.
- makeHedgehog** `make_hedgehog`, if **true**: reads minkmap with given *smooth* and standard parameters, writes ds9 region file in *outascii* containing lines at angles of regions with  $q_2 > 0.01$ , threshold given by *lineScale* sets length scale (length =  $smooth/2 \cdot |q_2|/lineScale$ ), creates fits file in *outlinedens* with number of lines crossing every block. Also makes bubbles (see below). Default: false
- lineThresh** `line_thresh`, threshold of line density for bubble detection/threshold for point pattern generation (only fields above this considered). Default: 20
- lineScale** `line_scale`, factor by which length of lines is divided. Default: 0.3
- makeBubbles** `make_bubbles`, if **true**: reads line density Fitsfile with given *filePrefix*, thresholds and *smooth* value, then takes every block with line number higher than threshold given by *lineThresh* and  $|q_2| > |q'_2|$  at about three times larger *smooth* (see switch *smooth* in code), creates ds9 region file in *outascii* with boxes centered around those blocks and width = 2·smooth. Writes every box into object file in *.objectDIR* and names of boxes into maskfile in working directory. Default: false
- filewithoutWCS** `filewithoutWCS`, to be used for FITS files that were created with e.g. `gimp` and do not contain any coordinate keyword. Simple placeholder settings are added and file is saved with a second .fits ending. Useful for the ds9 “lock: frame: WCS” tool when displaying several images in parallel
- readkey** `WCSkeynames.push_back([...])`, read given key in addition to standard WCS keywords from infile and pass on to new files

Syntax of files containing objects:

- Files containing boxes to be in-/excluded ("objects", usually located in *objectDIR*): One box per line with the following four space- or tab-separated numbers in pixels: RA/x center, DEC/y center, x width, y width (ds9 coordinates in pixels of original images, y axis flipped compared to internal coords). Several boxes possible for one object.
- maskfile: Contains name of one object (see above) in every line. For every such object an equally named file containing boxes in objectDIR is expected. Lines beginning with '#' are ignored.
- combination-file: Contains name of one maskfile in every line listing bubbles of one size, starting at lowest size.
- histfile: Contains name of one ds9 point-objectlist in every line. For every such line an equally named file containing point-regions in ds9 image coordinates in objectDIR is expected. Lines beginning with '#' are ignored.
- Files containing point-regions are expected to be of the form  $*([ra],[dec])^*$  in the image coordinate system of the raw images. ds9 format is preferred.

Example commands:

Typical Minkowski map for one threshold, scale 10 pixels:

```
./banana in myfile.fits filePrefix halpha outminmap ./minmapfolder/ s 2 smooth 10 maxt 5
```

Typical Minkowski map averaging several thresholds, scale 10 pixels:

```
./banana in myfile.fits filePrefix halpha outminmap ./minmapfolder/ s 2 smooth 10 3d true  
avg true maxt 40 mint 0.1 numt 9
```

Typical banana (for eroded/dilated image):

```
./banana in myfile.fits filePrefix halpha outascii ./results/ makeBanana true s 2 3d true avg  
true maxt 20 mint 0.1 numt 17 mask allObjects erd 3
```

Typical peach (requires Minkmaps to exist):

```
./banana in myfile.fits filePrefix halpha outascii ./results/ s 2 3d true maxt 40 mint 0.1 numt  
9 avg true makePeach true mask ./objectlists/allObjects
```

Typical region-PNGs (for eroded/dilated image):

```
./banana in myfile.fits filePrefix halpha outPNGs ./PNGfolder/ objectDIR ./objects/ erd 3  
monochrome false greenfile mygreenfile.fits bluefile mybluefile.fits mask ./objectlists/usethese.txt
```

Typical hedgehog:

```
./banana in myfile.fits filePrefix halpha outlinedens ./linedens/ outminmap ./minmapfolder/  
outascii ./results/ objectDIR ./objects/ makeHedgehog true s 2 smooth 40 mint 0.1 maxt 40  
numt 9 3d true avg true lineScale 0.4 lineThresh 20
```

Typical bubbles:

```
./banana in myfile.fits filePrefix halpha outlinedens ./linedens/ outminmap ./minmapfolder/  
outascii ./results/ objectDIR ./objects/ makeBubbles true smooth 40 mint 0.1 maxt 40 numt  
9 lineScale 0.4 lineThresh 21
```

Typical histogram:

```
./banana in myfile.fits filePrefix halpha outascii ./results/ stars ./files/allObjectLists maxt
```

1. mint -1. numt 100 makeHist true histapp aSpecificName

Typical pointspread:

./banana in myFileWithSameSizeAndCoords.fits filePrefix halpha outascii ./results/ make-Pointsread true smooth 250 stars ./files/allObjectLists

Typical point pattern:

./banana in myfile.fits filePrefix halpha outascii ./results/ outlinedens ./linedens/ makePattern linedensity smooth 40 s 2 avg true lineScale 0.3 lineThresh 12

Typical region combination:

./banana in myFileOrElseItCrashes.fits outascii ./results/ objectDIR ./objects/ combineRegions true combination bubbles\_sorted\_listoflists mask bubbles\_sorted\_combined\_list