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).

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 ψ_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 *outpointspread*.

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-ccollischon.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 origenal-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, usually wavelength. Default: “unspecified”‘
stars	histfile, list with one ds9 region file located in *objectDIR* per line containing 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. Default: 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	outfilename/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. Default: ./
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 ψ_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

makePointspread make_pointspread, 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 *outpointspread*. Default: false

makePattern make_patternFromImage, linesorminkmap, Accepts ”linedensity”, ”minkmap”, ”infile”, or ”infile_log” as follow-up commands, creates a 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]”). Infile 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

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 with 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-

Pointspread 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 combineRegions true combination bubbles_sorted_listoflists mask bubbles_sorted_combined_list